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Furukawa et al.

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(54) **NOZZLE PLATE AND METHOD OF MANUFACTURING NOZZLE PLATE**

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(73) Assignee: **Fujifilm Corporation**, Tokyo (JP)

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(51) **Int. Cl.**
B41J 2/135 (2006.01)
B41J 2/14 (2006.01)

(52) **U.S. Cl.** **347/45**; 347/47

(58) **Field of Classification Search** 347/45, 347/47

See application file for complete search history.

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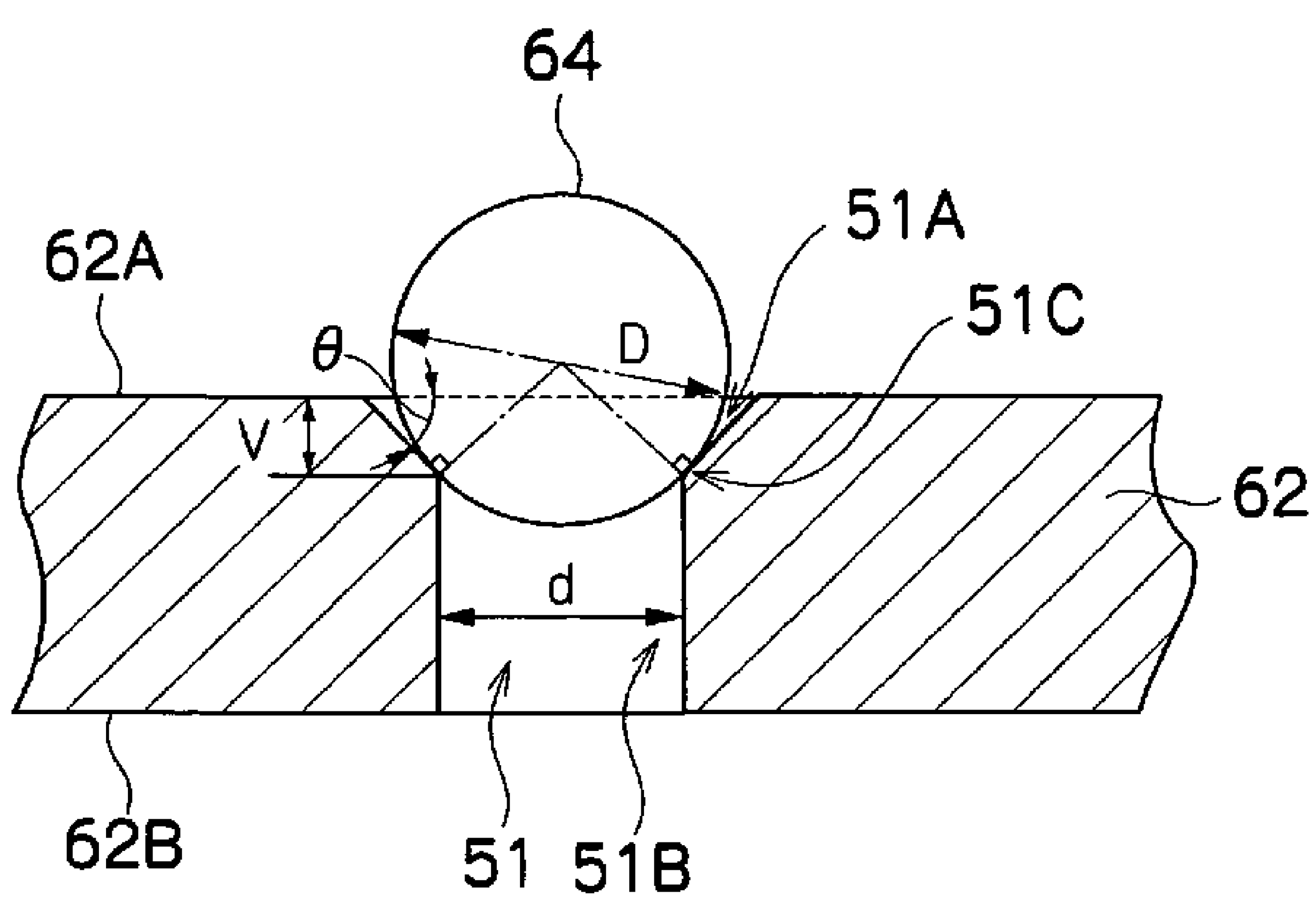
(57) **ABSTRACT**

The method manufactures a nozzle plate in which a liquid-repelling film is formed on a surface of a nozzle forming substrate having nozzle holes for ejecting liquid droplets, the surface being on a droplet ejection side of the nozzle forming substrate. The method includes the steps of: a spreading step of spreading sealing members for sealing the nozzle holes, over the surface of the nozzle forming substrate on the droplet ejection side; a drawing step of drawing the sealing members by suction through the nozzle holes, from another side of the nozzle forming substrate reverse to the droplet ejection side; a first removal step of removing a surplus of the sealing members present on the surface of the nozzle forming substrate on the droplet ejection side; an application step of applying a liquid-repelling agent onto the surface of the nozzle forming substrate on the droplet ejection side; a curing step of curing the liquid-repelling agent applied to the surface of the nozzle forming substrate on the droplet ejection side; and a second removal step of removing the sealing members from the nozzle holes.

6 Claims, 7 Drawing Sheets



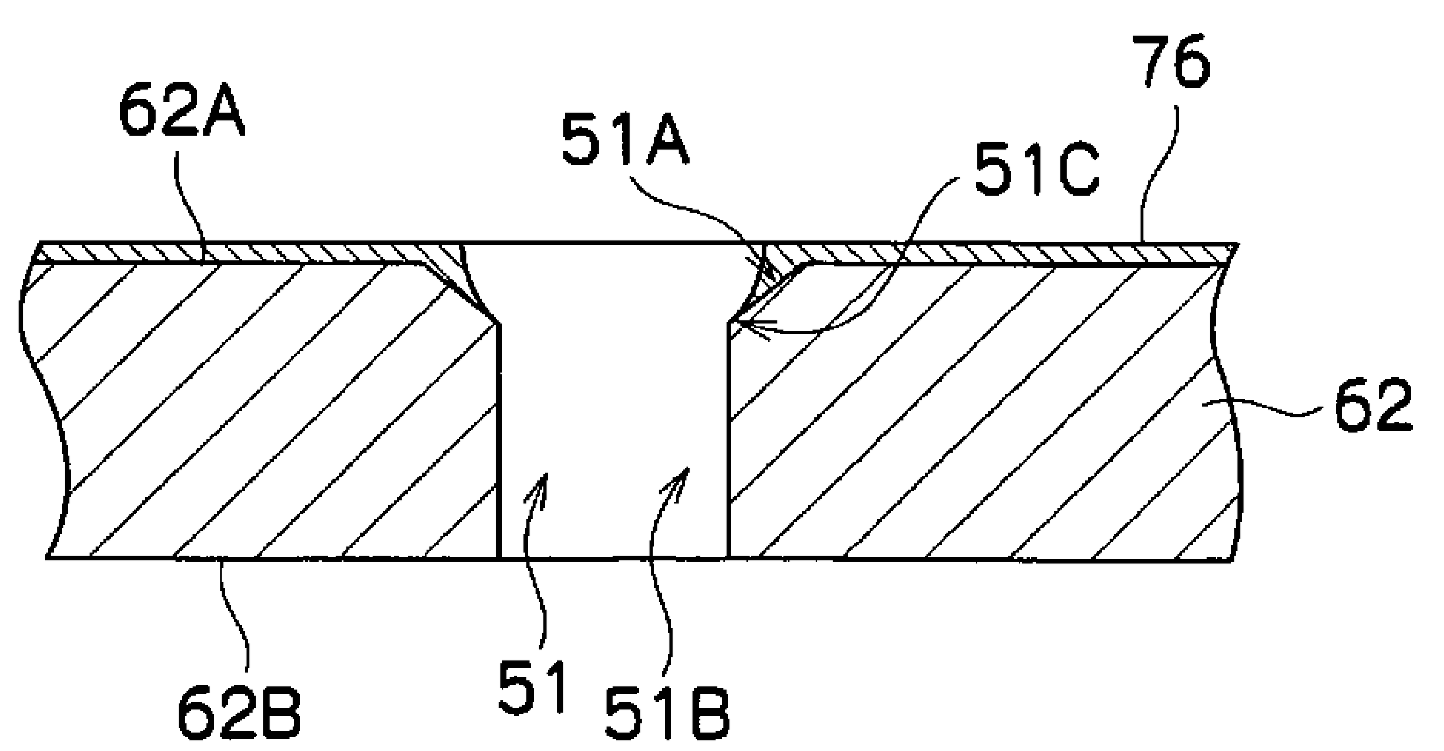


FIG.1

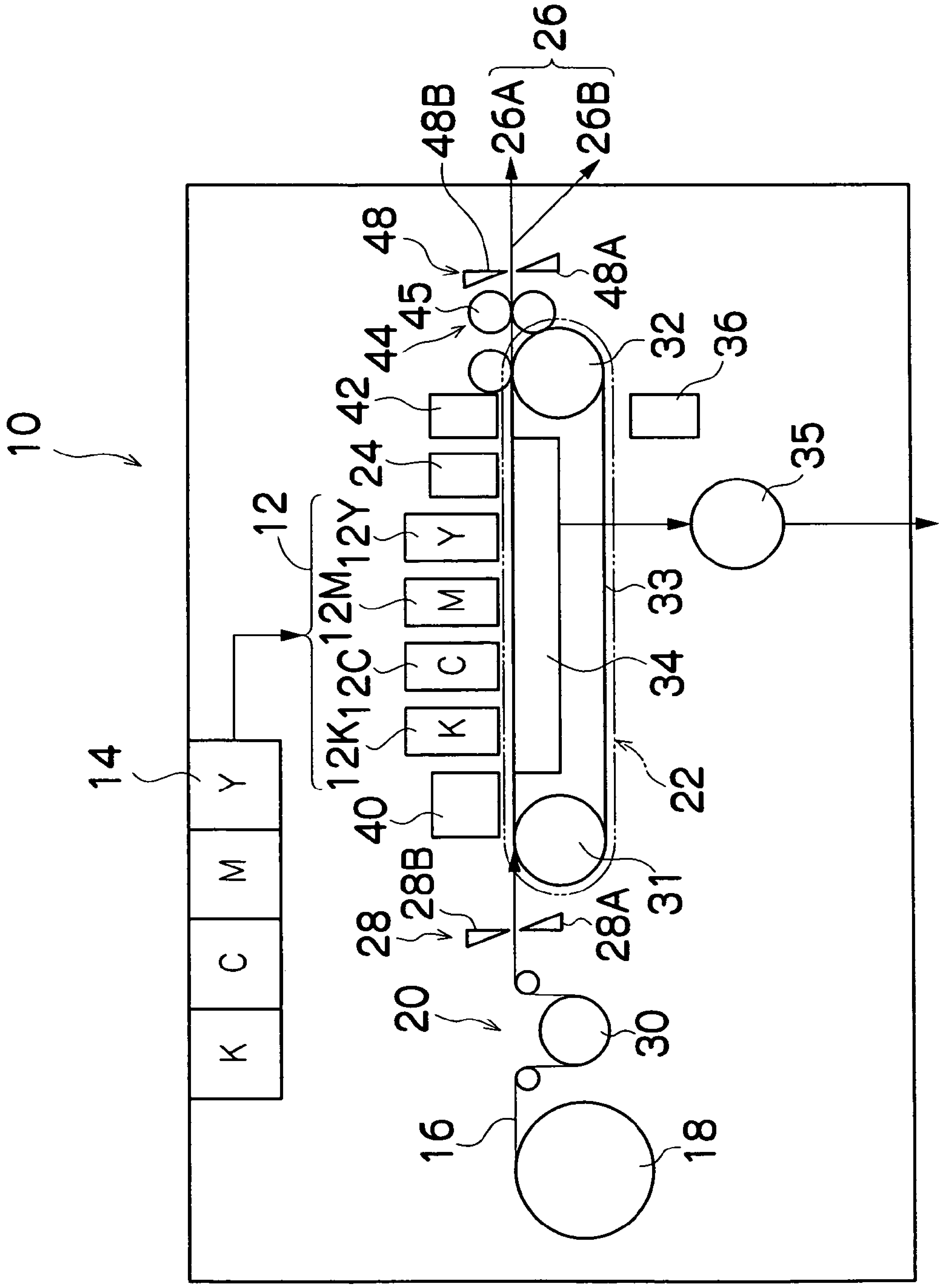

10
12
12K
12C
12M
12Y
14
K
C
M
Y
16
18
20
22
24
26
26A
26B
28
28A
28B
30
31
32
33
34
35
36
40
42
44
45
48
48A
48B

FIG.2

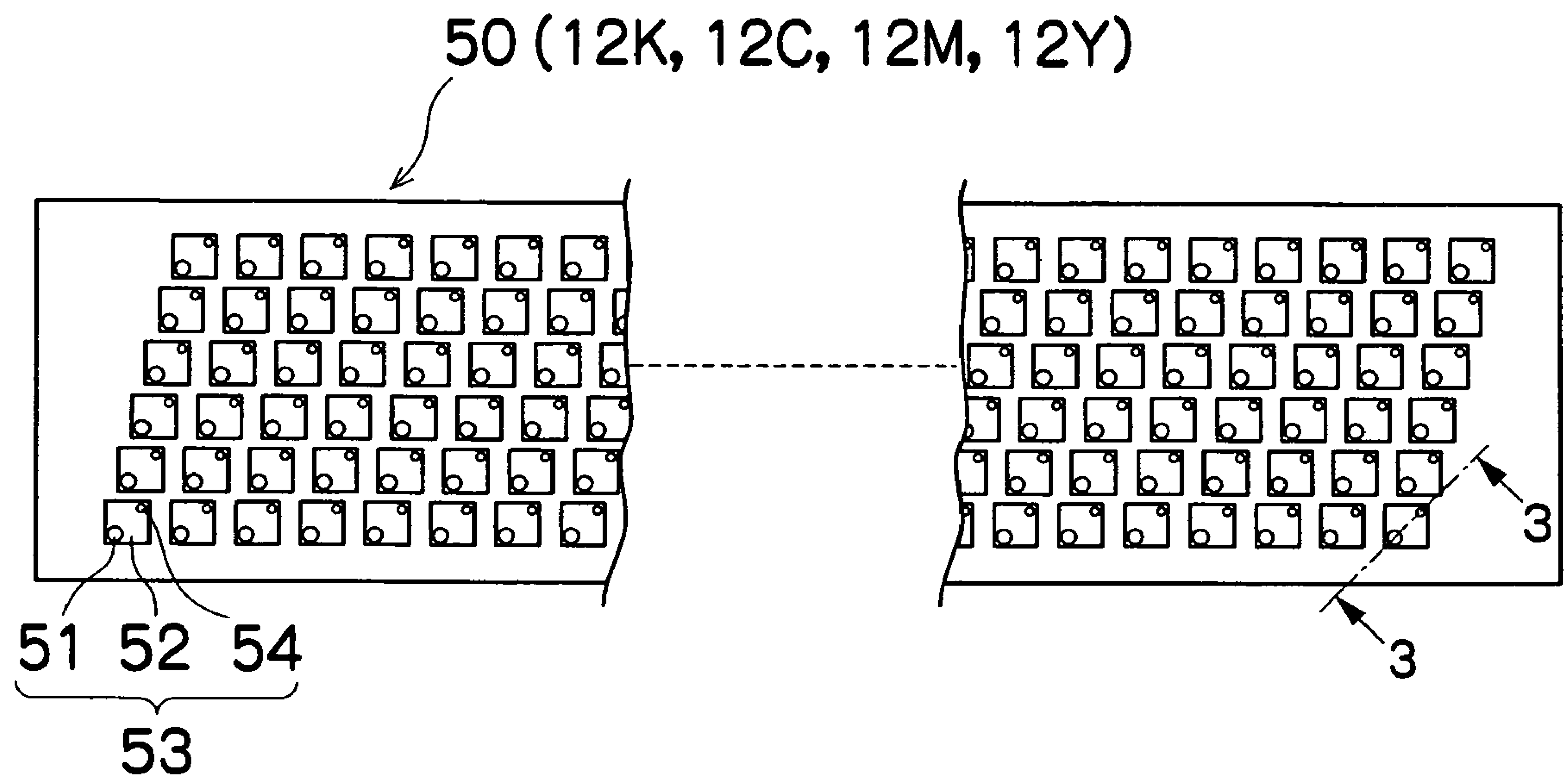


FIG.3

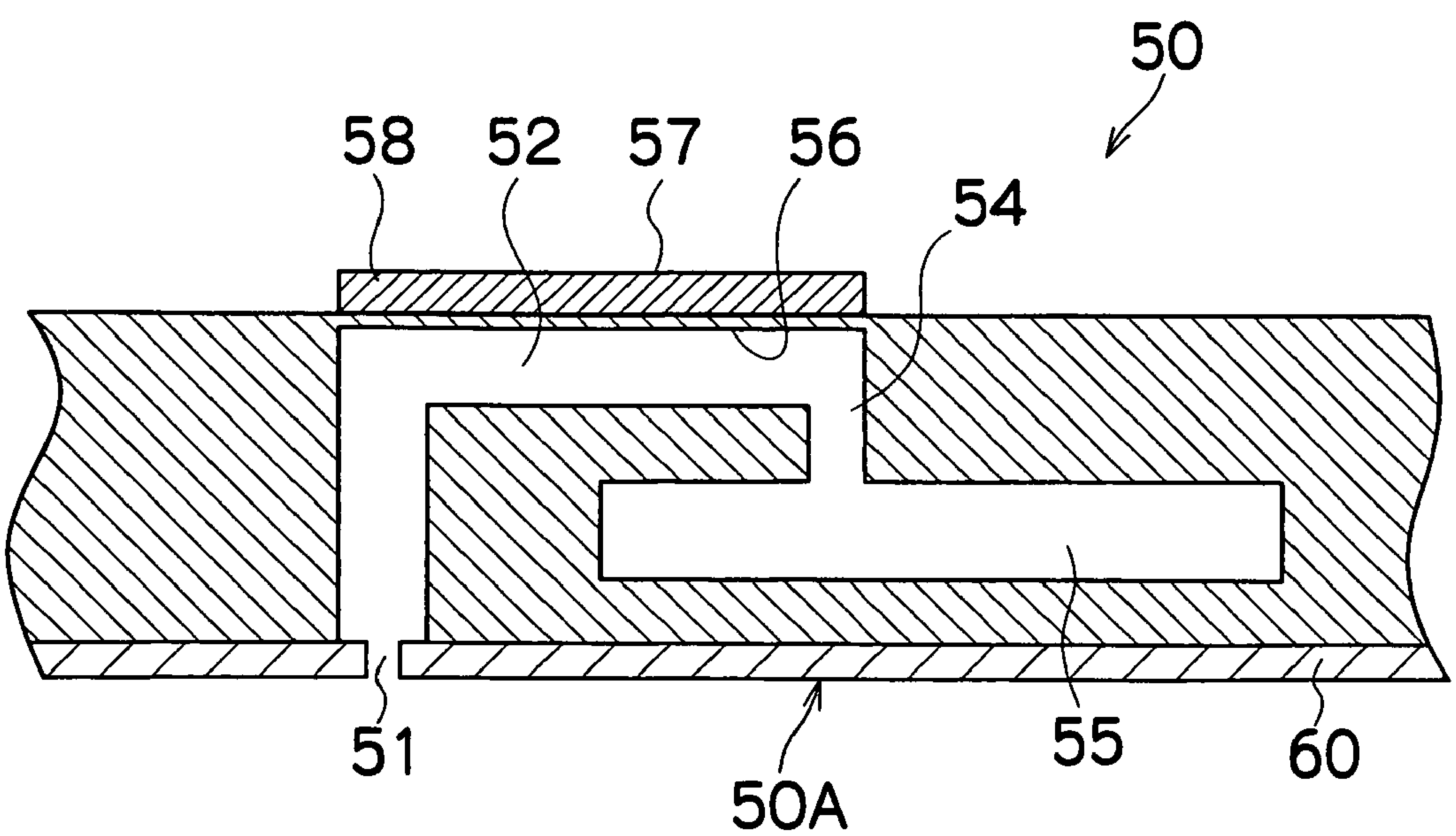


FIG.4

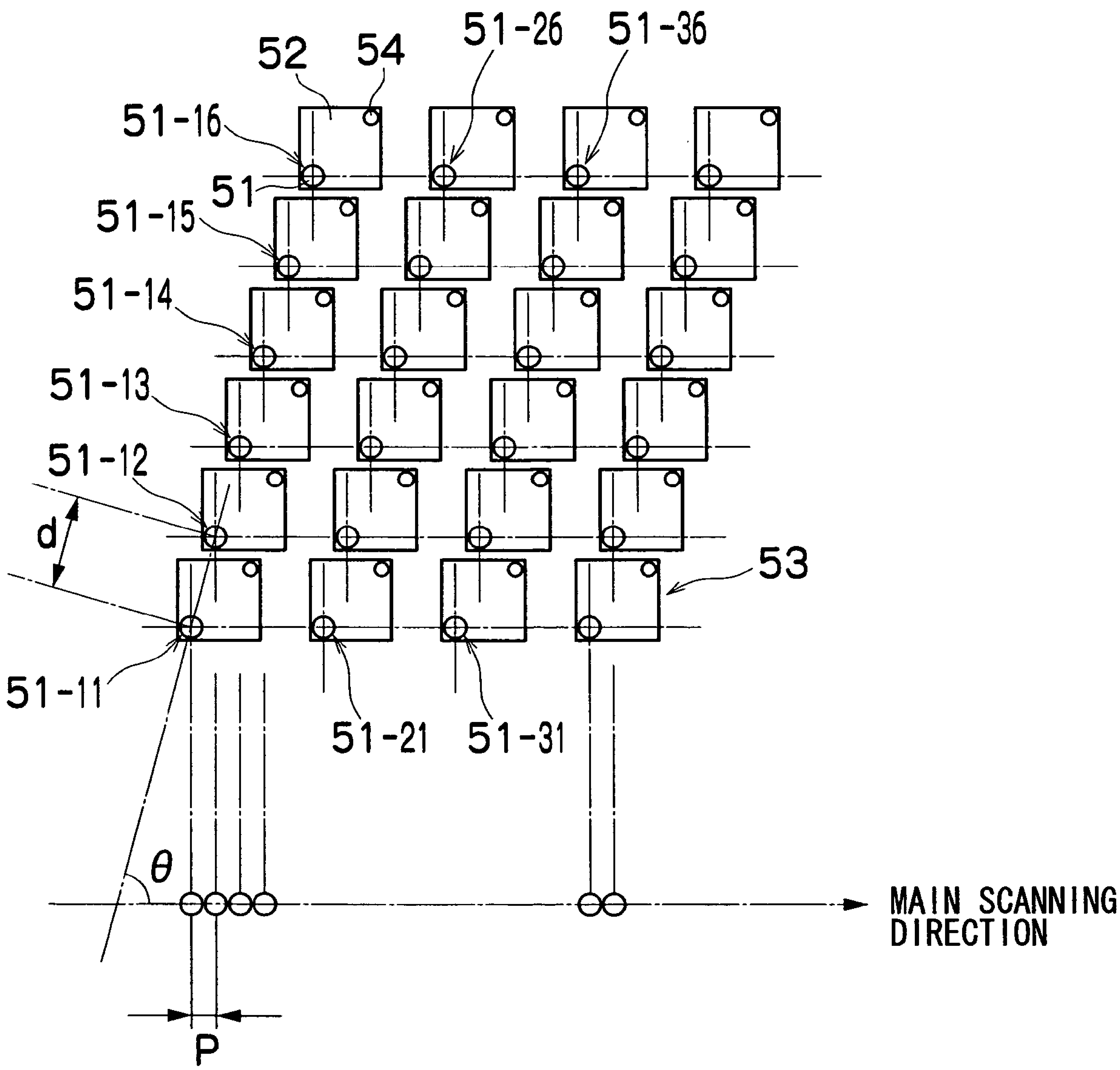

52
54
51-26
51-36
51-16
51
51-15
51-14
51-13
51-12
d
53
51-11
51-21
51-31
θ
MAIN SCANNING DIRECTION
P

FIG.5A

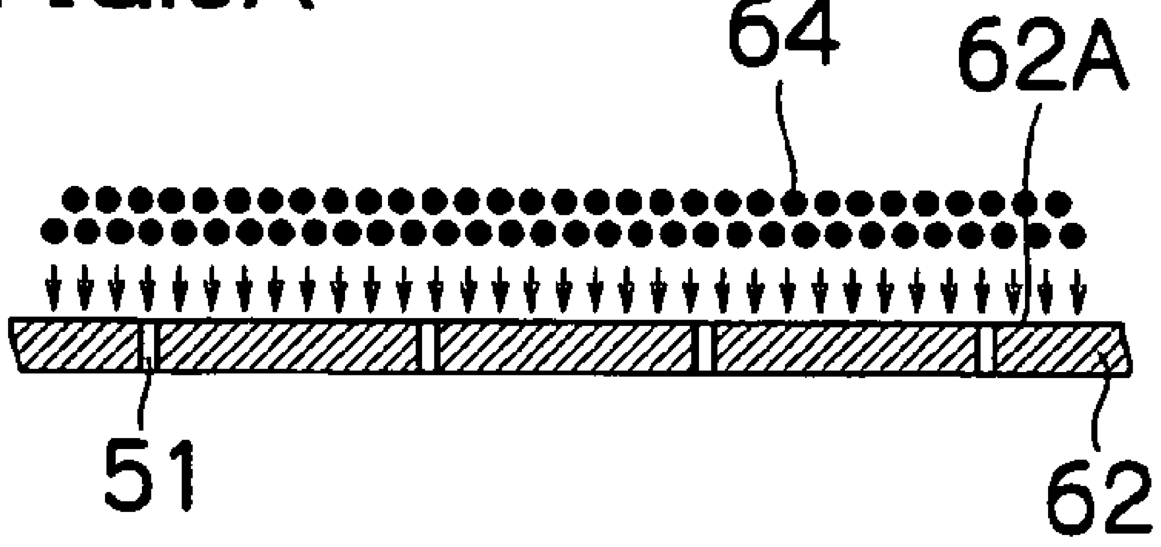


FIG.5B

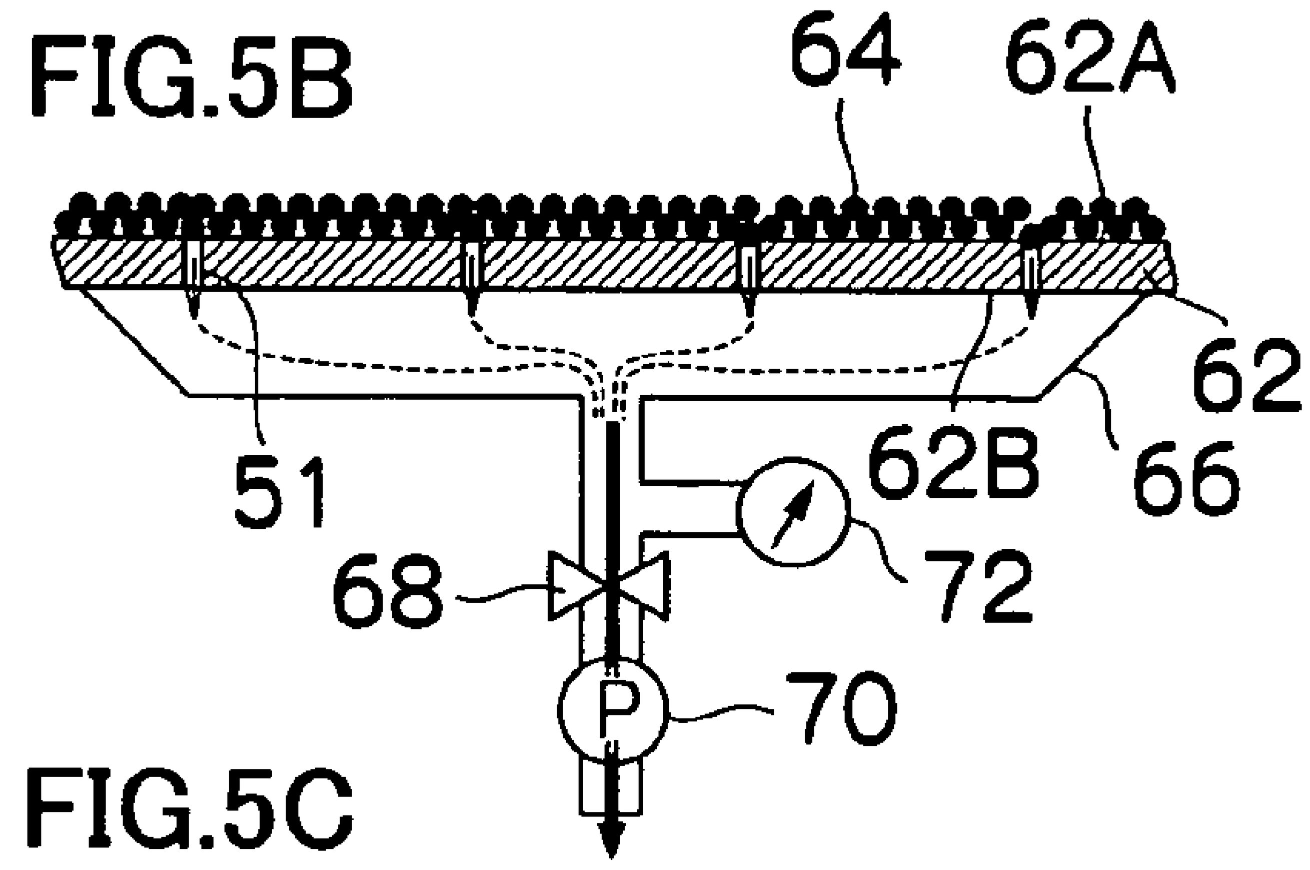


FIG.5C

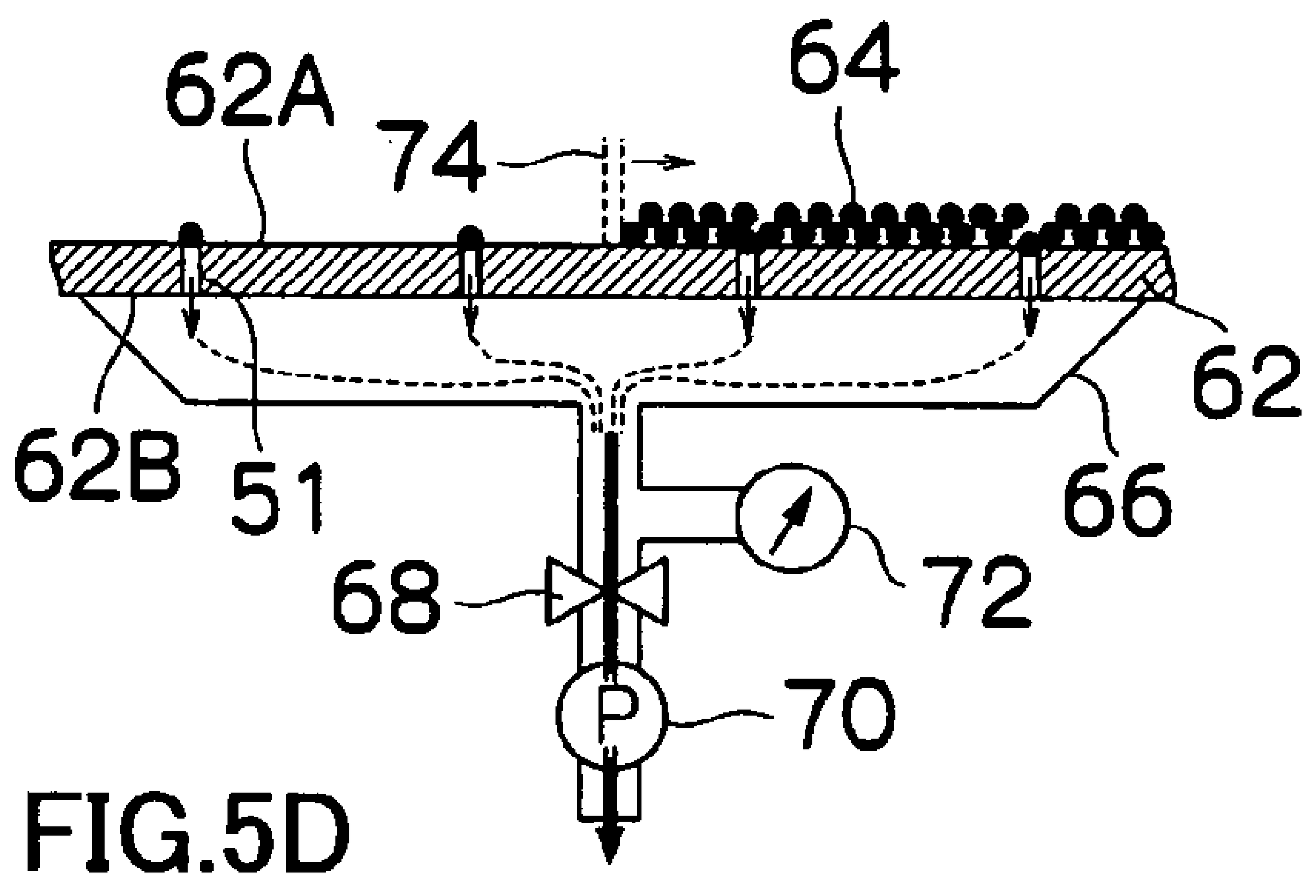


FIG.5D

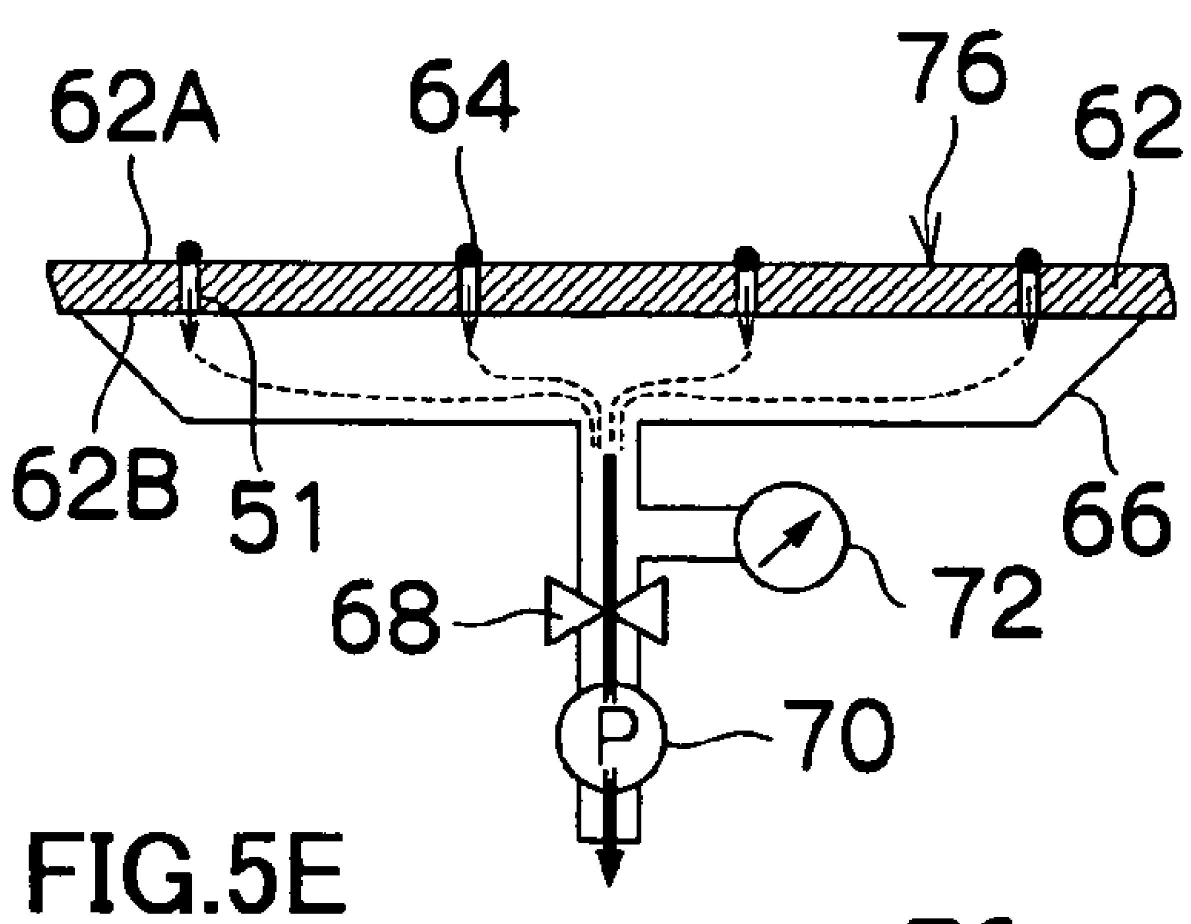


FIG.5E

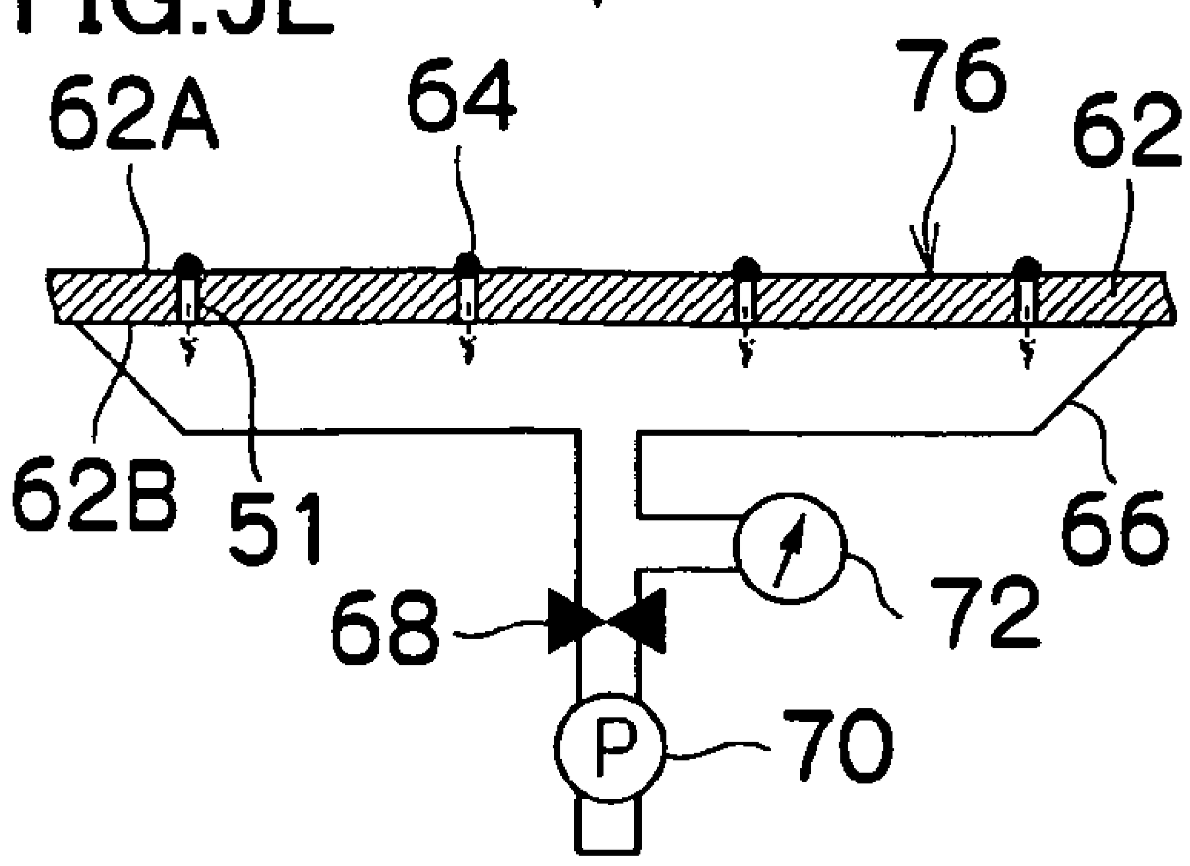


FIG.5F

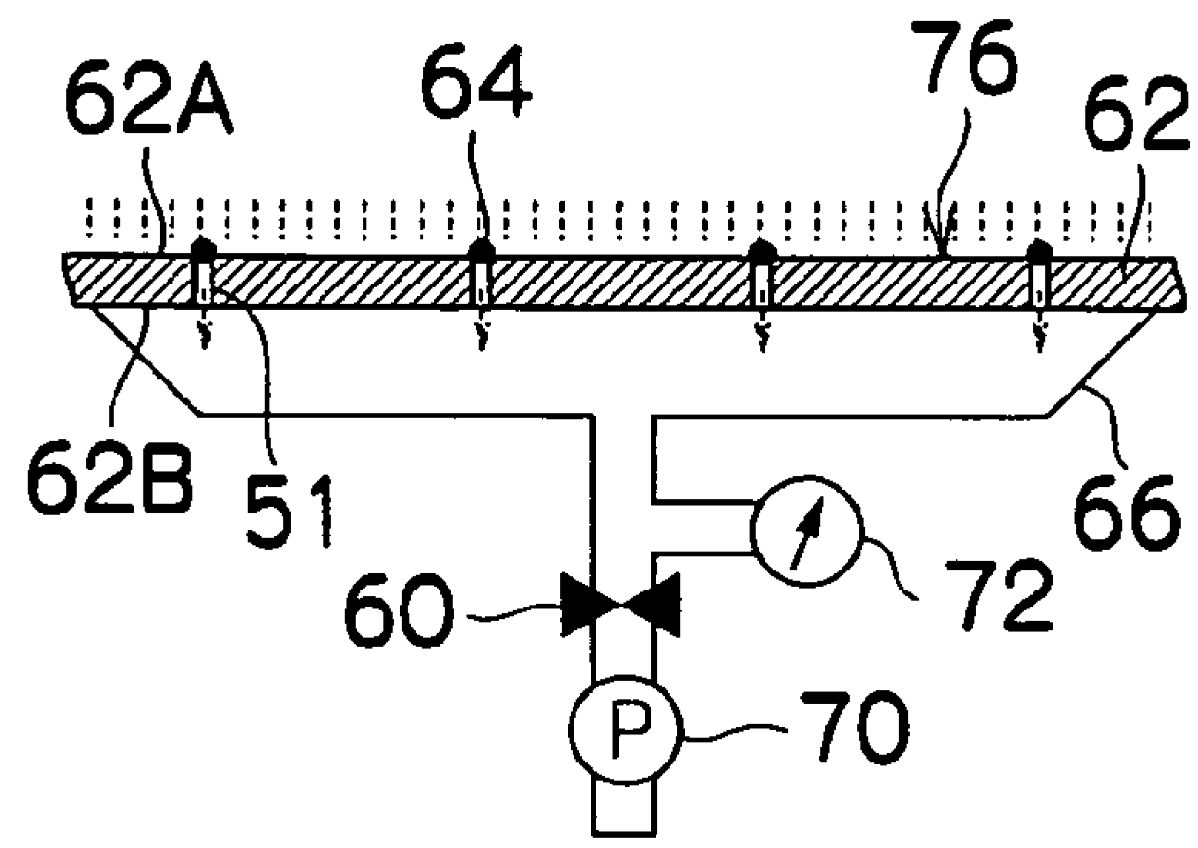


FIG.5G

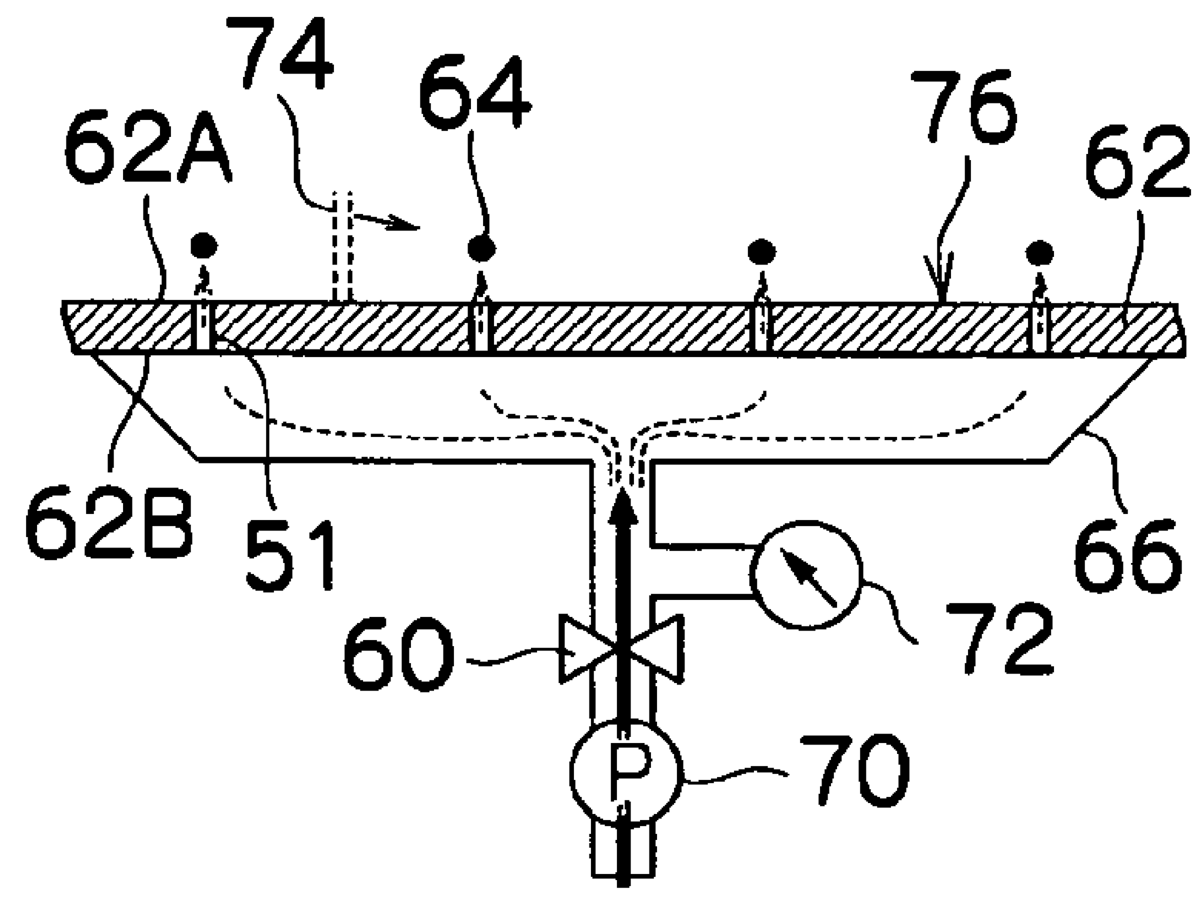


FIG.5H

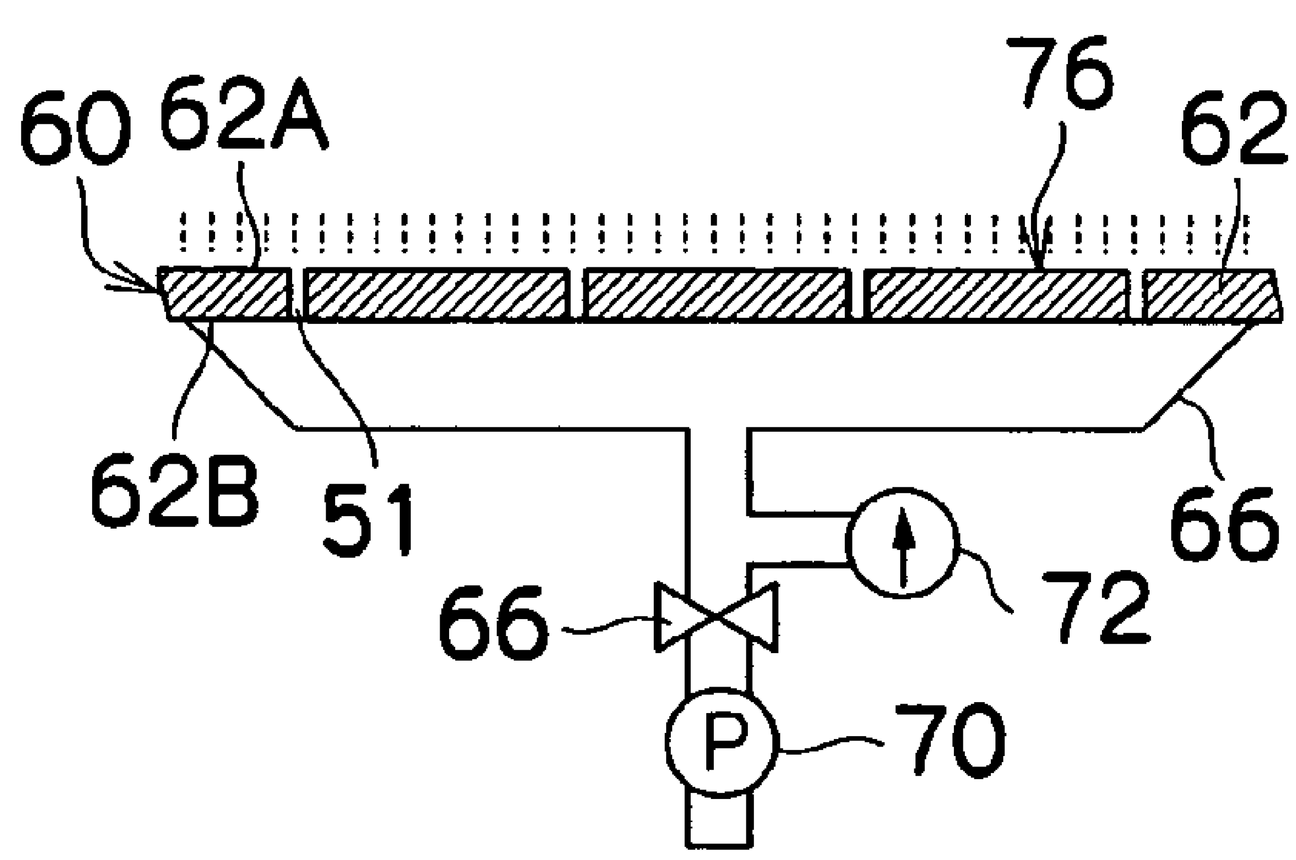


FIG.6

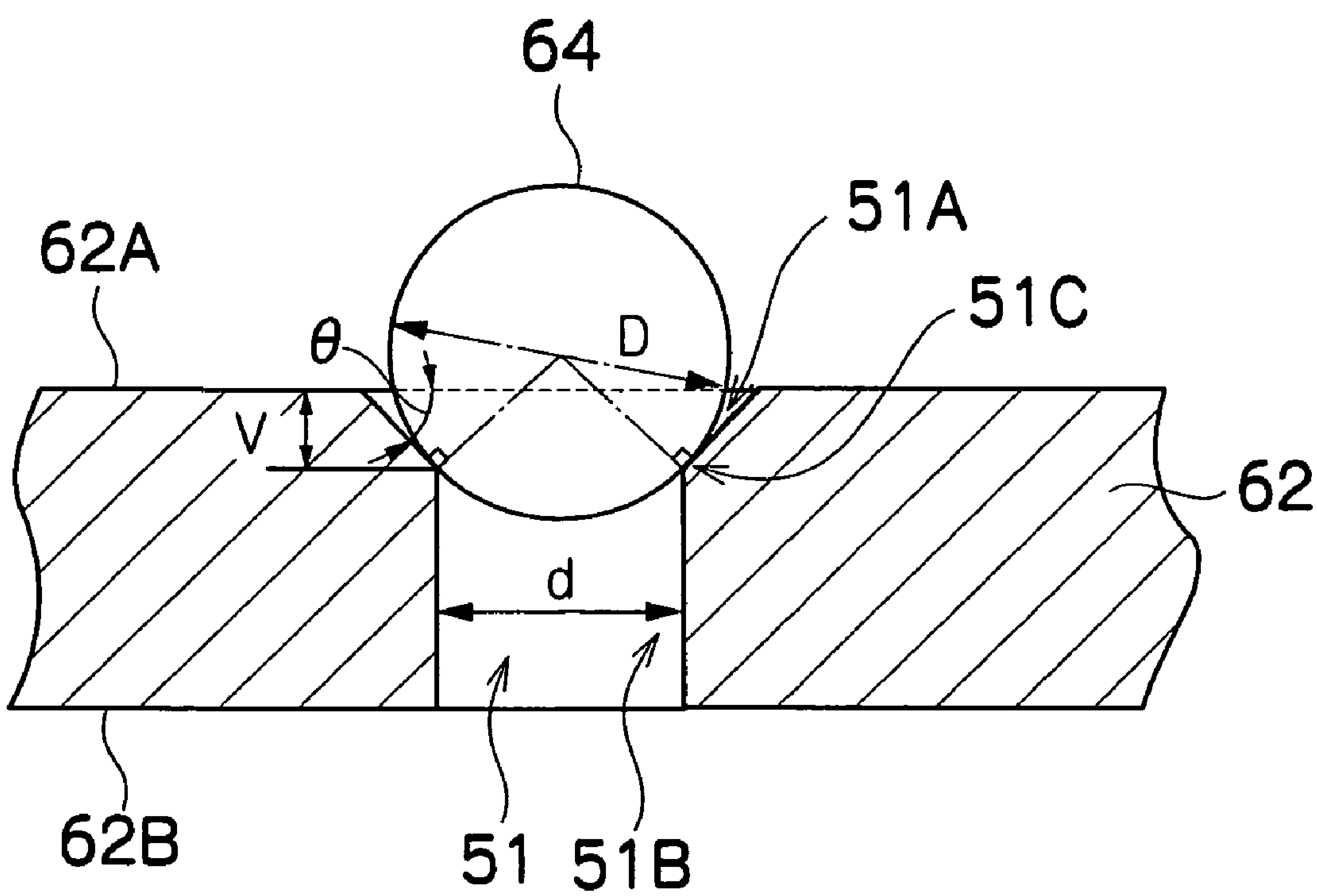


FIG.7

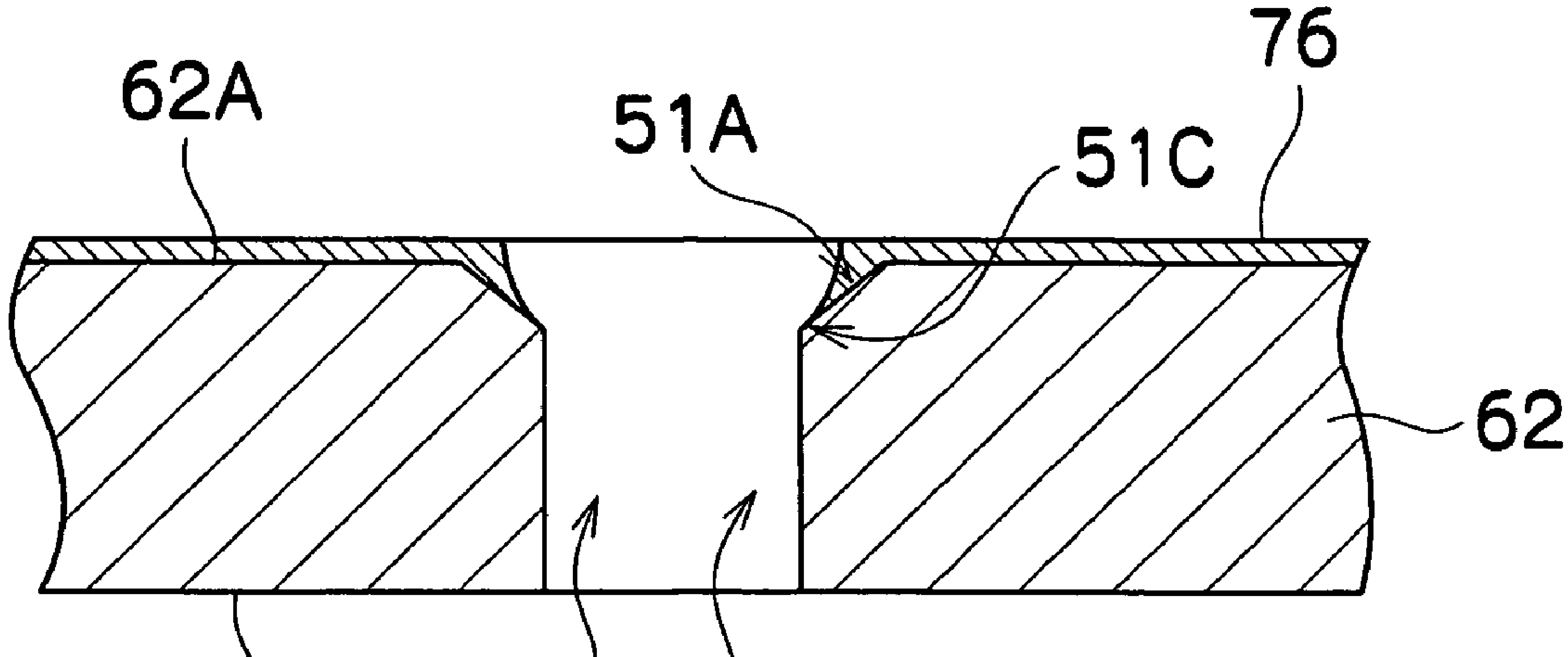


FIG.8A

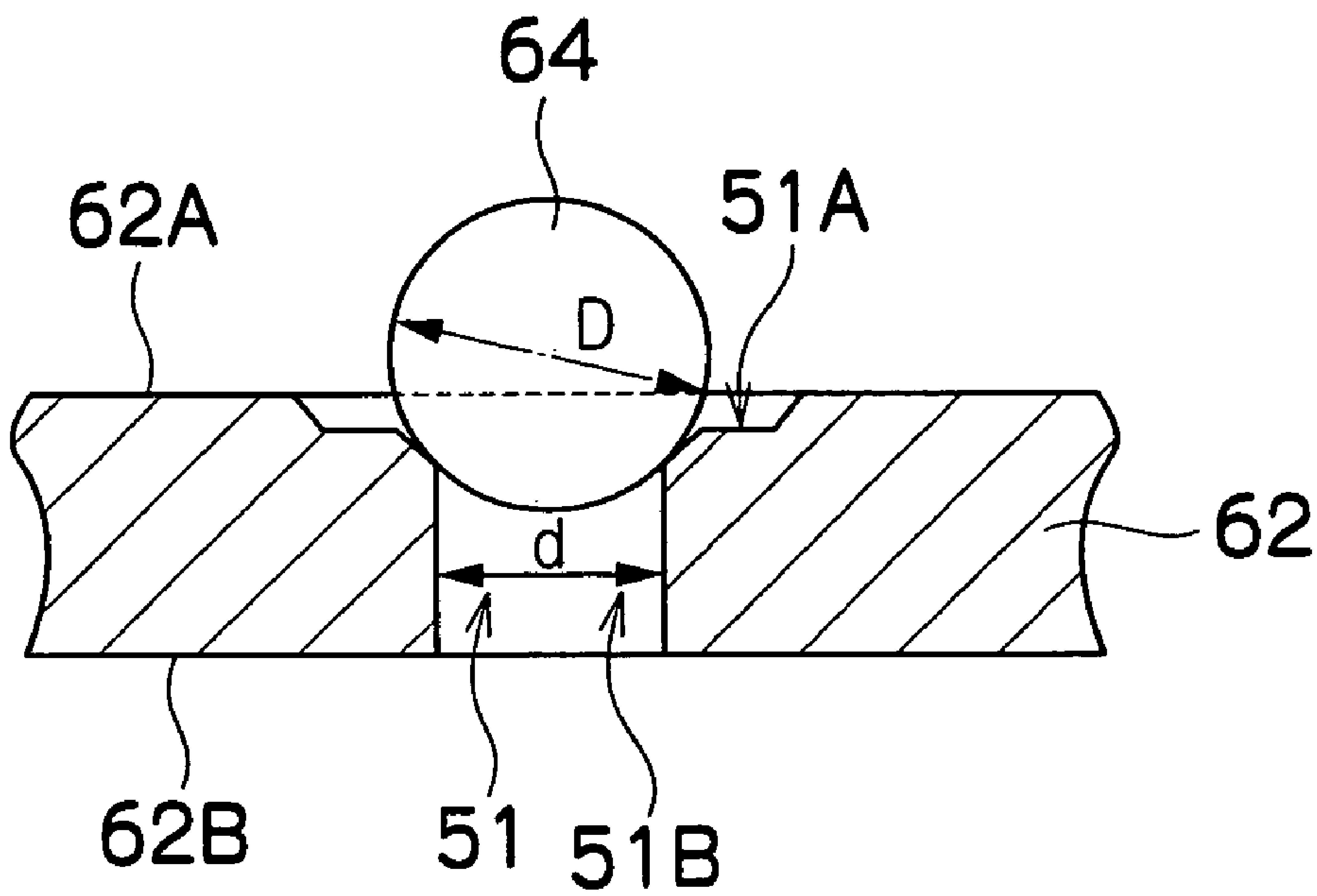


FIG.8B

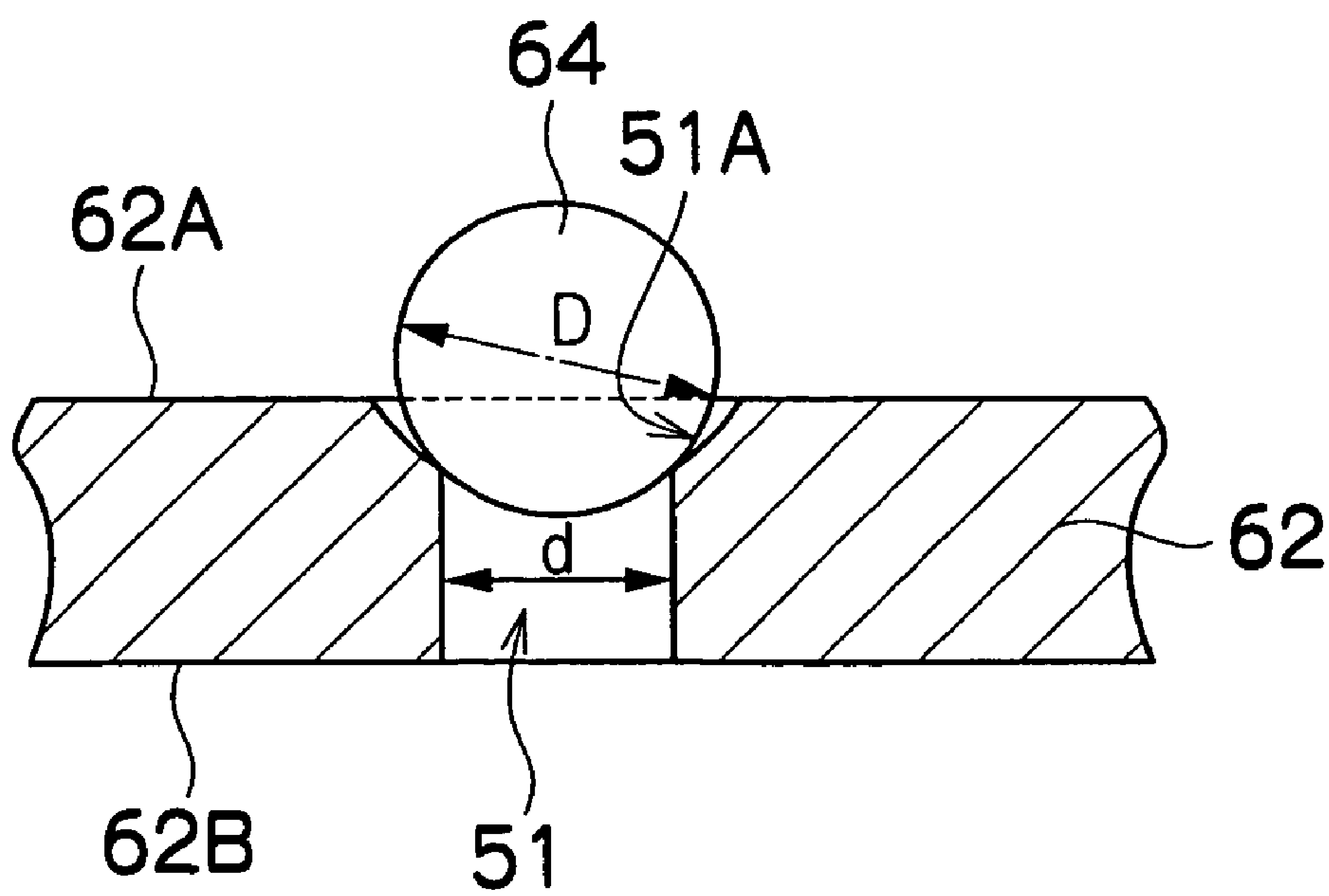


FIG.9

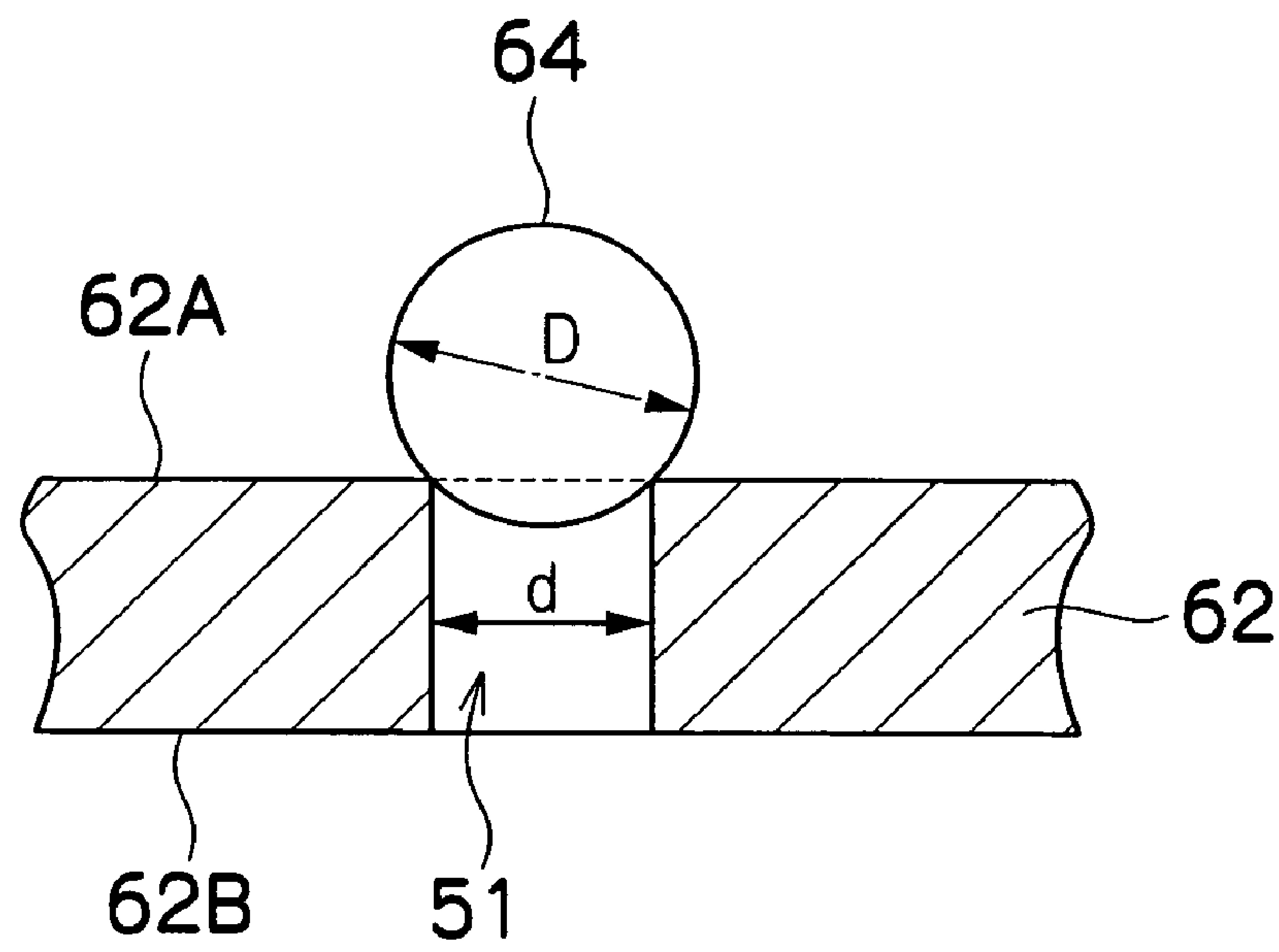
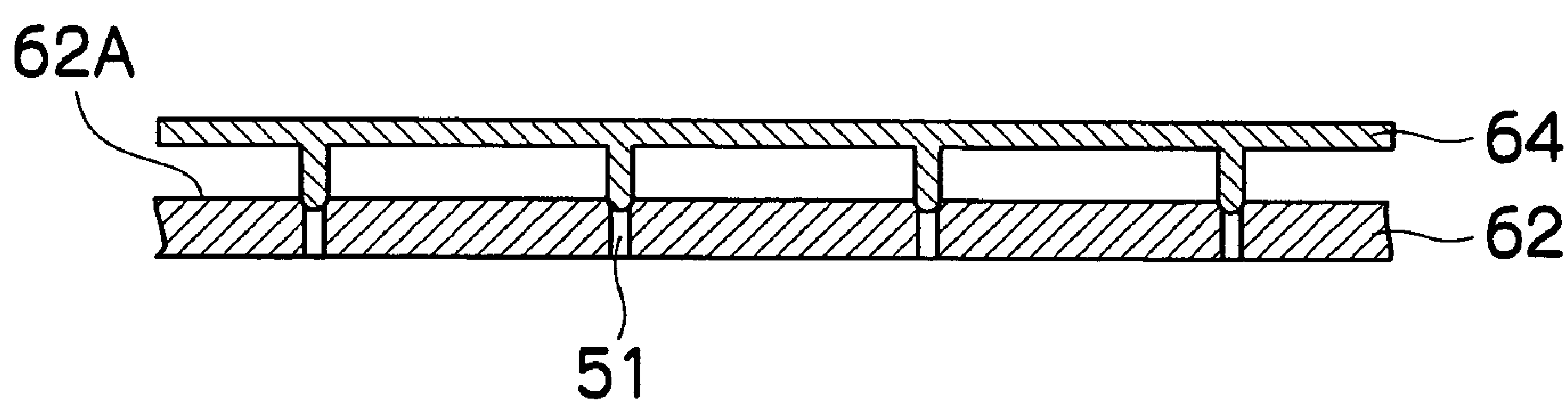


FIG.10



NOZZLE PLATE AND METHOD OF MANUFACTURING NOZZLE PLATE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a nozzle plate and a method of manufacturing a nozzle plate, and more particularly, to a method of manufacturing a nozzle plate in which a liquid-repelling film is formed on the surface thereof on the droplet ejection side.

2. Description of the Related Art

An inkjet type of image forming apparatus comprises a print head having a nozzle plate in which a plurality of nozzles (nozzle holes) are formed, and the image forming apparatus forms an image on a recording medium by ejecting ink droplets from these nozzles.

In order to stabilize the direction of flight of the ink droplets ejected from the nozzles, a liquid-repelling film is conventionally formed on the surface of the nozzle plate on the droplet ejection side. This is because, if there are ink droplets attached to the surface of the nozzle plate on the ink droplet ejection side (and in particular, in the periphery of the nozzles), then they can affect the direction of flight of the ink droplets ejected from the nozzles. By forming the liquid-repelling film, the ink droplets adhering to the surface of the nozzle plate on the ink droplet ejection side can be removed more readily by means of a blade or the like.

As a method of manufacturing a nozzle plate of this kind, Japanese Patent Application Publication No. 9-76492, for example, discloses a method in which a dry film resist made of a corrosion-resistant high polymer resin, such as a photosensitive film, or the like, is filled into the nozzles, the dry film is made to project by cutting by etching, and a surface treatment layer is then formed, whereupon the dry film is removed.

However, in the method in which the resist is filled into the nozzles, there is a problem in that the number of manufacturing steps for the nozzle plate increases and the work becomes more complicated. In particular, if the nozzle plate is large in size or complicated in shape, then the process of manufacturing the nozzle plate becomes more complicated and this leads to an increased number of manufacturing steps.

Furthermore, Japanese Patent Application Publication No. 2004-181883 discloses a method in which a liquid-repelling treatment liquid is applied onto the ink ejection surface of the nozzle plate by spin-coating, while introducing air into the nozzle holes from the other side of the nozzle plate reverse to the ink ejection surface, whereupon the nozzle plate is heat treated.

However, in the method in which the liquid-repelling treatment liquid is applied while introducing air into the nozzle holes, it is difficult to apply a highly viscous treatment liquid, and to form a thick film of the treatment liquid, due to the effects of the air flow, and therefore it is difficult to form a secure liquid-repelling film on the surface of the nozzle plate. Furthermore, if the nozzle plate is large in size, or is made to contain a large number of nozzles, then it is difficult to control the air pressure, due to the deformation of the nozzle plate as a result of the air pressure.

SUMMARY OF THE INVENTION

The present invention has been contrived in view of the foregoing circumstances, an object thereof being to simplify

the process of manufacturing a nozzle plate in which a liquid-repelling film is formed on the surface on the droplet ejection side.

In order to attain the aforementioned object, the present invention is directed to a method of manufacturing a nozzle plate in which a liquid-repelling film is formed on a surface of a nozzle forming substrate having nozzle holes for ejecting liquid droplets, the surface being on a droplet ejection side of the nozzle forming substrate, the method comprising the steps of: a spreading step of spreading sealing members for sealing the nozzle holes, on the surface of the nozzle forming substrate on the droplet ejection side; a drawing step of drawing the sealing members by suction through the nozzle holes, from another side of the nozzle forming substrate reverse to the droplet ejection side; a first removal step of removing a surplus of the sealing members present on the surface of the nozzle forming substrate on the droplet ejection side; an application step of applying a liquid-repelling agent onto the surface of the nozzle forming substrate on the droplet ejection side; a curing step of curing the liquid-repelling agent applied to the surface of the nozzle forming substrate on the droplet ejection side; and a second removal step of removing the sealing members from the nozzle holes.

According to the present invention, it is possible readily to seal off the nozzle holes by means of the sealing members, by drawing the sealing members spread over the surface of the nozzle forming substrate on the droplet ejection side, by suction through the nozzle holes. Furthermore, it is also possible to remove the sealing members readily from the nozzle holes, after applying the liquid-repelling agent to the surface of the nozzle forming substrate on the droplet ejection side. Consequently, the process of manufacturing the nozzle plate formed with the liquid-repelling film on the surface on the droplet ejection side is simplified. Furthermore, it is also possible to reuse the sealing members, and therefore the manufacturing costs of the nozzle plates can be reduced.

Preferably, the curing step includes a semi-curing step of changing the liquid-repelling agent to a semi-cured state, and a full-curing step of changing the liquid-repelling agent from the semi-cured state to a fully cured state; and the liquid-repelling agent applied to the surface of the nozzle forming substrate on the droplet ejection side is changed to the semi-cured state before the second removal step, and is then changed to the fully cured state after the second removal step. According to this aspect of the present invention, it is possible to readily remove the sealing members that seal off the nozzle holes.

Preferably, the drawing step comprises a measurement step of measuring a value of suction pressure of the suction; and the drawing step is performed until the measured value of the suction pressure becomes not less than a prescribed value. According to this aspect of the present invention, it is possible to confirm the sealed state of the nozzle holes by means of the sealing members, on the basis of the suction pressure, and therefore the nozzle holes can be sealed in a reliable fashion.

Preferably, the nozzle holes have at least partially tapered shapes in which internal diameters of the nozzle holes become larger toward ends thereof on the surface of the nozzle forming substrate on the droplet ejection side. According to this aspect of the present invention, when the sealing members are drawn by suction through the nozzle holes from the opposite side to the droplet ejection side of the nozzle forming substrate, then the sealing members enter readily into the tapered sections of the nozzle holes, and hence the nozzle holes can be sealed readily.

Preferably, the sealing members have a substantially spherical shape. According to this aspect of the present invention, it is possible to seal the nozzle holes readily.

Preferably, the sealing members are made of elastic bodies. According to this aspect of the present invention, it is possible to make the sealing members adhere closely to the nozzle holes without creating gaps, and hence the nozzle holes can be sealed in a reliable fashion.

In order to attain the aforementioned object, the present invention is also directed to a nozzle plate, comprising: a nozzle forming substrate which has nozzle holes for ejecting liquid droplets, the nozzle holes having tapered sections in which internal diameters of the nozzle holes become larger toward ends thereof on a surface of the nozzle forming substrate on a droplet ejection side; and a liquid-repelling film which is formed on the surface of the nozzle forming substrate on the droplet ejection side and is also formed on surfaces of the tapered sections.

According to the present invention, the liquid droplets are not liable to adhere to the tapered sections of the nozzle holes, and the ejection characteristics, such as the volume and flight direction of the liquid droplets ejected from the nozzle holes, are stabilized.

Preferably, the liquid-repelling film formed on the surfaces of the tapered sections becomes thicker toward the ends of the tapered sections on the surface of the nozzle forming substrate on the droplet ejection side. According to this aspect of the present invention, the wear resistance of the liquid-repelling film formed on the tapered sections is improved.

According to the present invention, it is possible readily to seal off the nozzle holes by means of the sealing members, by drawing the sealing members spread over the droplet ejection side of the nozzle forming substrate, by suction through the nozzle holes. Furthermore, it is also possible to remove the sealing members readily from the nozzle holes, after applying the liquid-repelling agent to the surface of the nozzle forming substrate on the droplet ejection side. Consequently, the process of manufacturing the nozzle plate formed with the liquid-repelling film on the surface on the droplet ejection side is simplified. Furthermore, it is also possible to reuse the sealing members, and therefore the manufacturing costs of the nozzle plates can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

The nature of this invention, as well as other objects and advantages thereof, will be explained in the following with reference to the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures and wherein:

FIG. **1** is a general compositional view showing an inkjet recording apparatus according to the present invention;

FIG. **2** is a plan perspective diagram showing an embodiment of the structure of a print head;

FIG. **3** is a cross-sectional diagram along line **3**-**3** in FIG. **2**;

FIG. **4** is an enlarged view showing an embodiment of the nozzle arrangement in the print head shown in FIG. **2**;

FIGS. **5**A to **5**H are illustrative diagrams showing steps of manufacturing a nozzle plate;

FIG. **6** is an enlarged cross-sectional diagram of a nozzle hole in a nozzle forming substrate;

FIG. **7** is an enlarged cross-sectional diagram of the nozzle hole in the nozzle forming substrate;

FIGS. **8**A and **8**B are enlarged cross-sectional diagrams showing further modes of a nozzle hole;

FIG. **9** is an enlarged cross-sectional diagram showing a further mode of a nozzle hole; and

FIG. **10** is a cross-sectional diagram showing a further mode of a sealing member.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

General Composition of Inkjet Recording Apparatus

FIG. **1** is a general schematic drawing of an inkjet recording apparatus which forms an image forming apparatus according to the present invention. As shown in FIG. **1**, the inkjet recording apparatus **10** comprises: a print unit **12** having a plurality of print heads **12**K, **12**C, **12**M, and **12**Y for ink colors of black (K), cyan (C), magenta (M), and yellow (Y), respectively; an ink storing and loading unit **14** for storing inks of K, C, M and Y to be supplied to the print heads **12**K, **12**C, **12**M, and **12**Y; a paper supply unit **18** for supplying recording paper **16**; a decurling unit **20** for removing curl in the recording paper **16** supplied from the paper supply unit **18**; a suction belt conveyance unit **22** disposed facing the nozzle face (ink droplet ejection face) of the print unit **12**, for conveying the recording paper **16** while keeping the recording paper **16** flat; a print determination unit **24** for reading the printed result produced by the print unit **12**; and a paper output unit **26** for outputting image-printed recording paper (printed matter) to the exterior.

In FIG. **1**, a magazine for rolled paper (continuous paper) is shown as an embodiment of the paper supply unit **18**; however, more magazines with paper differences such as paper width and quality may be jointly provided. Moreover, papers may be supplied with cassettes that contain cut papers loaded in layers and that are used jointly or in lieu of the magazine for rolled paper.

In the case of a configuration in which roll paper is used, a cutter **28** is provided as shown in FIG. **1**, and the roll paper is cut to a desired size by the cutter **28**. The cutter **28** has a stationary blade **28**A, whose length is not less than the width of the conveyor pathway of the recording paper **16**, and a round blade **28**B, which moves along the stationary blade **28**A. The stationary blade **28**A is disposed on the reverse side of the printed surface of the recording paper **16**, and the round blade **28**B is disposed on the printed surface side across the conveyance path. When cut paper is used, the cutter **28** is not required.

In the case of a configuration in which a plurality of types of recording paper can be used, it is preferable that an information recording medium such as a bar code and a wireless tag containing information about the type of paper is attached to the magazine, and by reading the information contained in the information recording medium with a predetermined reading device, the type of paper to be used is automatically determined, and ink-droplet ejection is controlled so that the ink-droplets are ejected in an appropriate manner in accordance with the type of paper.

The recording paper **16** delivered from the paper supply unit **18** retains curl due to having been loaded in the magazine. In order to remove the curl, heat is applied to the recording paper **16** in the decurling unit **20** by a heating drum **30** in the direction opposite from the curl direction in the magazine. The heating temperature at this time is preferably controlled so that the recording paper **16** has a curl in which the surface on which the print is to be made is slightly round outward.

The decurled and cut recording paper **16** is delivered to the suction belt conveyance unit **22**. The suction belt conveyance unit **22** has a configuration in which an endless belt **33** is set around rollers **31** and **32** so that the portion of the endless belt **33** facing at least the nozzle face of the print unit **12** and the sensor face of the print determination unit **24** forms a plane.

The belt **33** has a width that is greater than the width of the recording paper **16**, and a plurality of suction apertures (not shown) are formed on the belt surface. A suction chamber **34** is disposed in a position facing the sensor surface of the print determination unit **24** and the nozzle surface of the print unit **12** on the interior side of the belt **33**, which is set around the rollers **31** and **32**, as shown in FIG. **1**. The suction chamber **34** provides suction with a fan **35** to generate a negative pressure, and the recording paper **16** on the belt **33** is held by suction.

The belt **33** is driven in the clockwise direction in FIG. **1** by the motive force of a motor (not shown) being transmitted to at least one of the rollers **31** and **32**, which the belt **33** is set around, and the recording paper **16** held on the belt **33** is conveyed from left to right in FIG. **1**.

Since ink adheres to the belt **33** when a marginless print job or the like is performed, a belt-cleaning unit **36** is disposed in a predetermined position (a suitable position outside the printing area) on the exterior side of the belt **33**. Although the details of the configuration of the belt-cleaning unit **36** are not shown, embodiments thereof include a configuration in which the belt **33** is nipped with cleaning rollers such as a brush roller and a water absorbent roller, an air blow configuration in which clean air is blown onto the belt **33**, or a combination of these. In the case of the configuration in which the belt **33** is nipped with the cleaning rollers, it is preferable to make the line velocity of the cleaning rollers different than that of the belt **33** to improve the cleaning effect.

The inkjet recording apparatus **10** can comprise a roller nip conveyance mechanism, in which the recording paper **16** is pinched and conveyed with nip rollers, instead of the suction belt conveyance unit **22**. However, there is a drawback in the roller nip conveyance mechanism that the print tends to be smeared when the printing area is conveyed by the roller nip action because the nip roller makes contact with the printed surface of the paper immediately after printing. Therefore, the suction belt conveyance in which nothing comes into contact with the image surface in the printing area is preferable.

A heating fan **40** is disposed on the upstream side of the print unit **12** in the conveyance pathway formed by the suction belt conveyance unit **22**. The heating fan **40** blows heated air onto the recording paper **16** to heat the recording paper **16** immediately before printing so that the ink deposited on the recording paper **16** dries more easily.

The print unit **12** is a so-called "full line head" in which a line head having a length corresponding to the maximum paper width is arranged in a direction (main scanning direction) that is perpendicular to the paper conveyance direction (sub-scanning direction). The print heads **12**K, **12**C, **12**M and **12**Y forming the print unit **12** are constituted by line heads in which a plurality of ink ejection ports (nozzles) are arranged through a length exceeding at least one edge of the maximum size recording paper **16** intended for use with the inkjet recording apparatus **10**.

The print heads **12**K, **12**C, **12**M, **12**Y corresponding to respective ink colors are disposed in the order, black (K), cyan (C), magenta (M) and yellow (Y), from the upstream side (left-hand side in FIG. **1**), following the direction of conveyance of the recording paper **16** (the paper conveyance direction). A color print can be formed on the recording paper **16** by ejecting the inks from the print heads **12**K, **12**C, **12**M, and **12**Y, respectively, onto the recording paper **16** while conveying the recording paper **16**.

The print unit **12**, in which the full-line heads covering the entire width of the paper are thus provided for the respective ink colors, can record an image over the entire surface of the recording paper **16** by performing the action of moving the recording paper **16** and the print unit **12** relatively to each other in the paper conveyance direction (sub-scanning direction) just once (in other words, by means of a single sub-scan). Higher-speed printing is thereby made possible and productivity can be improved in comparison with a shuttle type head configuration in which a recording head moves reciprocally in a direction (main scanning direction) which is perpendicular to the paper conveyance direction (sub-scanning direction).

Although the configuration with the KCMY four standard colors is described in the present embodiment, combinations of the ink colors and the number of colors are not limited to those. Light inks or dark inks can be added as required. For example, a configuration is possible in which print heads for ejecting light-colored inks such as light cyan and light magenta are added.

As shown in FIG. **1**, the ink storing and loading unit **14** has tanks for storing inks of the colors corresponding to the respective print heads **12**K, **12**C, **12**M and **12**Y, and the tanks are connected to the print heads **12**K, **12**C, **12**M and **12**Y, through tube channels (not shown). Moreover, the ink storing and loading unit **14** also comprises a notifying device (display device, alarm sound generator, or the like) for generating a notification if the remaining amount of ink has become low, as well as having a mechanism for preventing incorrect loading of ink of the wrong color.

The print determination unit **24** has an image sensor (line sensor and the like) for capturing an image of the ink-droplet deposition result of the print unit **12**, and functions as a device to check for ejection defects such as clogs of the nozzles in the print unit **12** from the ink-droplet deposition results evaluated by the image sensor.

The print determination unit **24** of the present embodiment is configured with at least a line sensor having rows of photoelectric transducing elements with a width that is greater than the ink-droplet ejection width (image recording width) of the print heads **12**K, **12**C, **12**M, and **12**Y. This line sensor has a color separation line CCD sensor including a red (R) sensor row composed of photoelectric transducing elements (pixels) arranged in a line provided with an R filter, a green (G) sensor row with a G filter, and a blue (B) sensor row with a B filter. Instead of a line sensor, it is possible to use an area sensor composed of photoelectric transducing elements which are arranged two-dimensionally.

The print determination unit **24** reads a test pattern image printed by the print heads **12**K, **12**C, **12**M, and **12**Y for the respective colors, and determines the ejection of each head. The ejection determination includes the presence of the ejection, measurement of the dot size, and measurement of the dot deposition position.

A post-drying unit **42** is disposed following the print determination unit **24**. The post-drying unit **42** is a device to dry the printed image surface, and includes a heating fan, for example. It is preferable to avoid contact with the printed surface until the printed ink dries, and a device that blows heated air onto the printed surface is preferable.

In cases in which printing is performed with dye-based ink on porous paper, blocking the pores of the paper by the application of pressure prevents the ink from coming contact with ozone and other substance that cause dye molecules to break down, and has the effect of increasing the durability of the print.

A heating/pressurizing unit **44** is disposed following the post-drying unit **42**. The heating/pressurizing unit **44** is a device to control the glossiness of the image surface, and the image surface is pressed with a pressure roller **45** having a predetermined uneven surface shape while the image surface is heated, and the uneven shape is transferred to the image surface.

The printed matter generated in this manner is outputted from the paper output unit **26**. The target print (i.e., the result of printing the target image) and the test print are preferably outputted separately. In the inkjet recording apparatus **10**, a sorting device (not shown) is provided for switching the outputting pathways in order to sort the printed matter with the target print and the printed matter with the test print, and to send them to paper output units **26**A and **26**B, respectively. When the target print and the test print are simultaneously formed in parallel on the same large sheet of paper, the test print portion is cut and separated by a cutter (second cutter) **48**. The cutter **48** is disposed directly in front of the paper output unit **26**, and is used for cutting the test print portion from the target print portion when a test print has been performed in the blank portion of the target print. The structure of the cutter **48** is the same as the first cutter **28** described above, and has a stationary blade **48**A and a round blade **48**B.

Although not shown, the paper output unit **26**A for the target prints is provided with a sorter for collecting prints according to print orders.

Structure of Print Heads

Next, the structure of the print head is described. The print heads **12**K, **12**M, **12**C and **12**Y provided for the respective ink colors have the same structure, and a reference numeral **50** is hereinafter designated to a representative embodiment of these print heads.

FIG. **2** is a plan view perspective diagram showing the embodiment of the structure of a print head **50**. FIG. **3** is a cross-sectional diagram (along line **3**-**3** in the FIG. **2**) showing the three-dimensional composition of one of droplet ejection elements (an ink chamber unit corresponding to one nozzle **51**).

The nozzle pitch in the print head **50** should be minimized in order to maximize the resolution of the dots printed on the surface of the recording paper. As shown in FIG. **2**, the print head **50** according to the present embodiment has a structure in which a plurality of ink chamber units (droplet ejection elements) **53**, each comprising a nozzle **51** forming an ink droplet ejection port, a pressure chamber **52** corresponding to the nozzle **51**, and the like, are disposed two-dimensionally in the form of a staggered matrix, and hence the effective nozzle interval (the projected nozzle pitch) as projected in the lengthwise direction of the print head (the direction perpendicular to the paper conveyance direction) is reduced and high nozzle density is achieved.

As shown in FIG. **2**, the planar shape of the pressure chamber **52** provided for each nozzle **51** is substantially a square, and the nozzle **51** and an inlet of supplied ink (supply port) **54** are disposed in both corners on a diagonal line of the square.

As shown in FIG. **3**, the nozzle surface (ink ejection surface) **50**A of the print head **50** is constituted by a nozzle plate **60** in which nozzles (nozzle holes) **51** are formed. The method of manufacturing the nozzle plate **60** is described later in detail.

Each pressure chamber **52** is connected through a supply opening **54** to a common flow channel **55**. The common flow channel **55** is connected to an ink tank (not shown), which is a base tank that supplies ink, and the ink supplied from the ink tank is delivered through the common flow channel **55** to the pressure chambers **52**.

An actuator **58** provided with an individual electrode **57** is joined to a pressure plate (common electrode) **56** which forms the upper face of each pressure chamber **52**. The actuator **58** is deformed when a drive voltage is supplied to the individual electrode **57** and the common electrode **56**, and the volume of the pressure chamber **52** is changed, thereby causing ink to be ejected from the nozzle **51**. A piezoelectric element including a piezoelectric body is suitable as the actuator **58**. When ink is ejected, new ink is supplied to the pressure chamber **52** from the common flow channel **55** through the supply port **54**.

As shown in FIG. **4**, the plurality of ink chamber units **53** having this structure are composed in a lattice arrangement, based on a fixed arrangement pattern having a row direction which coincides with the main scanning direction, and a column direction which, rather than being perpendicular to the main scanning direction, is inclined at a fixed angle of θ with respect to the main scanning direction. By adopting a structure wherein a plurality of ink chamber units **53** are arranged at a uniform pitch d in a direction having an angle θ with respect to the main scanning direction, the pitch P of the nozzles when projected to an alignment in the main scanning direction is $d \times \cos\theta$.

More specifically, the arrangement can be treated equivalently to one in which the respective nozzles **51** are arranged in a linear fashion at a uniform pitch P, in the main scanning direction. By means of this composition, it is possible to achieve a nozzle composition of high density, in which the nozzle columns projected to align in the main scanning direction reach a total of 2,400 per inch (2,400 nozzles per inch).

In a full-line head comprising rows of nozzles that have a length corresponding to the entire width of the image recordable width, the "main scanning" is defined as printing one line or one strip in the width direction of the recording paper (the direction perpendicular to the conveyance direction of the recording paper) by driving the nozzles in one of the following ways: (1) simultaneously driving all the nozzles; (2) sequentially driving the nozzles from one side toward the other; and (3) dividing the nozzles into blocks and sequentially driving the nozzles from one side toward the other in each of the blocks.

In particular, when the nozzles **51** arranged in a matrix such as that shown in FIG. **4** are driven, the main scanning according to the above-described (3) is preferred. More specifically, the nozzles **51-11**, **51-12**, **51-13**, **51-14**, **51-15** and **51-16** are treated as a block (additionally; the nozzles **51-21**, . . . , **51-26** are treated as another block; the nozzles **51-31**, . . . , **51-36** are treated as another block; . . .); and one line is printed in the width direction of the recording paper **20** by sequentially driving the nozzles **51-11**, **51-12**, . . . , **51-16** in accordance with the conveyance velocity of the recording paper **20**.

On the other hand, "sub-scanning" is defined as to repeatedly perform printing of one line (a line formed of a row of dots, or a line formed of a plurality of rows of dots) formed by the main scanning, while moving the full-line head and the recording paper relatively to each other.

In implementing the present invention, the arrangement of the nozzles is not limited to that of the embodiment illustrated. Moreover, a method is employed in the present embodiment where an ink droplet is ejected by means of the deformation of the actuator **58**, which is typically a piezoelectric element; however, in implementing the present invention, the method used for discharging ink is not limited, and instead of the piezo jet method, it is also possible to apply various types of methods, such as a thermal jet method where the ink is heated and bubbles are caused to form therein by means of a heat generating body such as a heater, ink droplets being ejected by means of the pressure applied by these bubbles.

Method for Manufacturing Nozzle Plate

FIGS. **5**A to **5**H are illustrative diagrams showing steps of manufacturing the nozzle plate **60**. Below the method of manufacturing the nozzle plate **60** which is characteristic of the present invention is described with reference to these diagrams.

Firstly, as shown in FIG. **5**A, a thin plate-shaped nozzle forming substrate **62** made of a metal, such as stainless steel, is processed to form nozzle holes (nozzles) **51** therein, by means of machine processing, laser processing, etching, or the like, and sealing members **64** for sealing off the nozzle holes **51** are spread over the surface (the ink ejection surface) **62**A of the nozzle forming substrate **62** on the ink ejection side. The sealing members **64** are constituted by elastic bodies having an approximately spherical shape, and the details of the sealing members **64** are described later.

Thereupon, as shown in FIG. **5**B, the sealing members **64** having been spread over the ink ejection surface **62**A are drawn by suction through the nozzle holes **51** from the side on the other surface (the ink flow channel surface) **62**B of the nozzle forming substrate **62** reverse to the ink ejection surface **62**A. For example, as shown in FIG. **5**B, the side on the ink flow channel surface **62**B of the nozzle forming substrate **62** is closed off with a hermetic cover **66**, a valve **68** is opened and a pump **70** is operated to provide suction, thereby sucking out the air of the side on the ink flow channel surface **62**B closed off with the hermetic cover **66** and drawing the sealing members **64** by suction through the nozzle holes **51**, while measuring the pressure of the side on the ink flow channel surface **62**B with a pressure gauge **72**. Consequently, a portion of the sealing members **64** having been spread over the ink ejection surface **62**A of the nozzle forming substrate **62** seal off the nozzle holes **51**A from the side on the ink ejection surface **62**A, while the remainder of the sealing members **64** remain on the ink ejection surface **62**A, as surplus sealing members **64**. It is also possible to draw the sealing members **64** by suction through the nozzle holes **51** from the side on the ink flow channel surface **62**B, at the same time as spreading the sealing members **64** over the ink ejection surface **62**A.

Next, as shown in FIG. **5**C, the ink ejection surface **62**A is scanned by an air curtain **74**, while continuing to apply suction from the side on the ink flow channel surface **62**B. This action removes the surplus sealing members **64** remaining on the ink ejection surface **62**A of the nozzle forming substrate **62** (in other words, the sealing members **64** that are not sealing off the nozzle holes **51**). The sealing members **64** removed by the air curtain **74** can be reused.

Thereupon, as shown in FIG. **5**D, the pressure (suction pressure) is measured with the pressure gauge **72**. If the value of the suction pressure measured with the pressure gauge **72** is less than a specified value (i.e., the measured pressure is between the atmospheric pressure and a specified pressure below the atmospheric pressure), then it is determined that there is a nozzle hole **51** that has not yet been sealed off by a sealing member **64**, and hence the process of spreading the sealing members **64** from the side on the ink ejection surface **62**A and drawing from the ink flow channel surface **62**B is carried out again. The process described above is repeated until the suction pressure measured by the pressure gauge **72** is equal to or greater than the specified value.

In this way, it is possible to confirm the sealed state of the nozzle holes **51** by means of the sealing members **64** on the basis of the pressure (suction pressure) measured with the pressure gauge **72**, and even if the nozzle holes **51** are very fine, the sealed state of the nozzle holes **51** by the sealing members **64** can be confirmed to a high degree of accuracy.

If the value of the suction pressure measured with the pressure gauge **72** is equal to or greater than the specified value (i.e., the measured pressure is equal to the specified pressure or further from the atmospheric pressure than the specified pressure), then it is determined that all of the nozzle holes **51** have been sealed off by the sealing members **64**, and a liquid-repelling agent **76** is then applied to the ink ejection surface **62**A of the nozzle forming substrate **62**. In this case, desirably, the pressure (negative pressure) of the side on the ink flow channel surface **62**B of the nozzle forming substrate **62** is maintained uniform, and furthermore, desirably, the valve **68** is closed and the pump **70** is halted, thereby closing off the side on the ink flow channel surface **62**B, which is hermetically sealed by the hermetic cover **66**, in such a manner that there are no effects due to the pressure fluctuations and mechanical vibrations in the pump **70**. Furthermore, if the nozzle forming substrate **62** is formed with a large number of nozzles, or if the nozzle forming substrate **62** is formed to a large size, then it is desirable that the pressure of the side on the ink flow channel surface **62**B is reduced (brought near to the atmospheric pressure) in comparison with the step shown in FIG. **5**B, and the liquid-repelling agent **76** is applied once the pressure has become uniform. This prevents warping of the nozzle forming substrate **62**, and makes it possible to apply the liquid-repelling agent **76** to the ink ejection surface **62**A of the nozzle forming substrate **62** in an even and uniform fashion.

The method of applying the liquid-repelling agent **76** may be spin-coating, vapor deposition, spraying, or the like. Spin-coating is more suitable for forming a thick film than vapor deposition or spraying. On the other hand, in the case of vapor deposition or spraying, there is a probability that the film is also formed on the surfaces of the sealing members **64**, and it is then necessary to clean the surfaces of the sealing members **64** before finally removing the sealing members **64**. Consequently, it is desirable to use a spin-coating method to apply the liquid-repelling agent **76** to the ink ejection surface **62**A of the nozzle forming substrate **62**.

Thereupon, as shown in FIG. **5**F, the liquid-repelling agent **76** having been applied to the ink ejection surface **62**A of the nozzle forming substrate **62** is cured (hardened). During this, the pressure (negative pressure) of the side on the ink flow channel surface **62**B of the nozzle forming substrate **62** is maintained in the same state as during the application of the liquid-repelling agent **76**. The conditions for curing the liquid-repelling agent **76** vary depending on the type of liquid-repelling agent **76** used.

In the present embodiment, if it is possible to set the liquid-repelling agent **76** to a state of increased viscosity (a semi-cured state), then it is desirable to set the liquid-repelling agent **76** to the semi-cured state at this stage, rather than to a fully cured state. If the liquid-repelling agent **76** is a thermally curable material, then it is possible to cure the liquid-repelling agent **76** to a semi-cured state by heating at a low temperature. For example, in the case of a liquid-repelling agent **76** having curing properties of 1 hour at a curing temperature of 180° C., then it is desirable that the liquid-repelling agent is heated for 1 hour at 100° C., or for 30 minutes at 120° C., for example. If the liquid-repelling agent **76** is curable by ultraviolet light, then it is desirable that the ultraviolet light irradiation time is shortened accordingly. If the liquid-repelling agent **76** requires heat treatment, then it is desirable that the heat treatment is not carried out at this point.

Thereupon, as shown in FIG. **5**G, the valve **68** is opened and the pump **70** is operated to provide positive pressure, and the pressure over the atmospheric pressure is applied to the sealing members **64** that are sealing the nozzle holes **51**, from the side on the ink flow channel surface **62**B, through the nozzle holes **51**. Thereby, the sealing members **64** are blown upward and removed from the nozzle holes **51**. These sealing members **64** are removed by the air curtain **74**. The sealing members **64** thus removed can be reused. It is also possible to remove the sealing members **64** from the nozzle holes **51** after inverting the nozzle forming substrate **62** in such a manner that the ink ejection surface **62**A faces in the downward direction in FIG. **5**G.

If the liquid-repelling agent **76** is in the semi-cured state, then as shown in FIG. **5**H, a process corresponding to the type of liquid-repelling agent **76** is carried out (namely, heating, irradiation of ultraviolet light, or the like), and the liquid-repelling agent **76** is thus converted to a fully cured state.

In this way, it is possible to manufacture a nozzle plate **60** having the liquid-repelling agent (liquid-repelling film) **76** formed on the ink ejection surface **62**A of the nozzle forming substrate **62** having the nozzle holes **51**. If burring occurs in the liquid-repelling agent **76** in the vicinity of the nozzle opening sections, during the removal of the sealing members **64** from the nozzle holes **51** in the step shown in FIG. **5**G, then desirably, this burring is removed by sandblasting, heat treatment, or the like.

Structure of Sealing Members

Next, the structure of the sealing members **64** is described. FIG. **6** is an enlarged cross-sectional diagram of the nozzle hole **51** in the nozzle forming substrate **62** in a state the nozzle hole **51** is sealed off by the sealing member **64**.

In the present embodiment, the sealing member **64** is an approximately spherical shape and is constituted by an elastic body made of silicone, polyimide, or the like. The nozzle hole **51** has a tapered section **51**A, in which the internal diameter of the nozzle hole **51** becomes larger toward the end thereof on the ink ejection surface **62**A, and a cylindrical section **51**B having the same diameter as the minimum diameter of the tapered section **51**A.

In order to stabilize the ejection characteristics, such as the volume and the speed of flight of the ink droplets ejected from the nozzle hole **51**, it is necessary to prevent the liquid-repelling agent **76** from entering into the cylindrical section **51**B of the nozzle hole **51**. Therefore, as shown in FIG. **6**, the nozzle hole **51** must be sealed off reliably, in such a manner that the sealing member **64** is caught at the section where the tapered section **51**A and the cylindrical section **51**B connect together, namely, the section having the minimum diameter in the tapered section **51**A (hereinafter referred to as the minimum diameter section **51**C). In other words, it is necessary to adopt a composition in which the sealing member **64** makes contact with the minimum diameter section **51**C of the nozzle hole **51**. Hence, if the angle of taper of the tapered section **51**A of the nozzle hole **51** is θ and the internal diameter of the minimum diameter section **51**C is d, then the diameter D of the sealing member **64** satisfies the following condition (1):

$$D \leq \frac{d}{\sin\theta}. \quad (1)$$

Furthermore, in order that the sealing members **64** can be removed readily from the nozzle holes **51** after applying the liquid-repelling agent **76** to the ink ejection surface **62**A of the nozzle forming substrate **62**, it is necessary to adopt a composition in which the center of each sealing member **64** is situated to the outside of the ink ejection surface **62**A of the nozzle forming substrate **62** (to the upper side in FIG. **6**), as shown in FIG. **6**. Therefore, if the depth of the tapered section **51**B in the nozzle hole **51** is v, then the diameter D of the sealing member **64** satisfies the following condition (2):

$$D \geqq \sqrt{d^2+4v^2}. \quad (2)$$

Consequently, the sealing member **64** satisfying the above-described conditions (1) and (2) is able to seal off the nozzle hole **51** reliably, in such a manner that the liquid-repelling agent **76** does not enter into the cylindrical section 5B of the nozzle hole **51**, while at the same time, the sealing member **64** can be removed readily from the nozzle hole **51** after application of the liquid-repelling agent **76**.

For example, if the angle of taper θ of the tapered section **51**A of the nozzle hole **51** is 45°, the depth v of the tapered section **51**A is 10 μm, and the internal diameter d of the minimum diameter section **51**C is 30 μm, then the diameter D of the sealing member **64** desirably satisfies the following condition (3):

$$36.1\ \mu m \leqq D \leqq 42.4\ \mu m. \quad (3)$$

FIG. **7** is an enlarged cross-sectional diagram of the nozzle hole **51** in the nozzle forming substrate **62** on which the liquid-repelling agent (liquid-repelling film) **76** has been formed on the ink ejection surface **62**A, in a state after the sealing members **64** (not shown in FIG. **7**) have been removed. By using the sealing member **64** that satisfies the above-described conditions (1) and (2), it is possible to remove the sealing member **64** readily from the nozzle hole **51**, as shown in FIG. **7**. The liquid-repelling agent (liquid-repelling film) **76** is formed on the surface of the tapered section **51**A of the nozzle hole **51**, following the external shape of the sealing member **64**, which is approximately spherical in shape. The liquid-repelling agent (liquid-repelling film) **76** is formed in such a manner that it gradually becomes thicker from the minimum diameter section **51**C, toward the ink ejection surface **62**. The liquid-repelling agent (liquid-repelling film) **76** formed on the tapered section **51**A of the nozzle hole **51** in this way is formed at a uniform depth in the nozzle hole **51**, and it has excellent resistance to wear.

Furthermore, in the present embodiment, if the film thickness t of the liquid-repelling agent **76** formed on the ink ejection surface **62**A of the nozzle forming substrate **62** is not of a negligible size compared to the depth v of the tapered section **51**A, then desirably, instead of the above-described condition (2), the following condition (4) is satisfied to take account of the film thickness t of the liquid-repelling agent **76**:

$$D \geqq \sqrt{d^2+4(v+t)^2}. \quad (4)$$

The tapered section **51**A of the nozzle hole **51** is not limited to having a linear shape as shown in FIGS. **6** and **7**, and it may also have a stepped shaped as shown in FIG. **8**A, or a curved shape as shown in FIG. **8**B.

In the present embodiment, since the sealing member **64** is constituted by an elastic body as described above, then the sealing member **64** makes close contact with the nozzle hole **51**, without producing any gaps, and is therefore able to seal off the nozzle hole **51** in a reliable fashion. Therefore, even if there is some variation in the dimensional accuracy of the nozzle holes **51**, this variation can be absorbed. The desirable value of the hardness of the sealing members **64** varies with factors such as the shape (internal diameter, etc.) of the nozzle holes **51**, the wetting properties and viscosity of the liquid-repelling agent **76**, the suction pressure applied from the side on the ink flow channel surface **62**B of the nozzle forming substrate **62**, and the like, but generally, the value of the hardness of the sealing members **64** is desirably A/60/1 or below.

Furthermore, desirably, the sealing members **64** are formed from a uniform material, and more desirably, this material is the same as that used in the nozzle forming substrate **62**. If the sealing members **64** and the nozzle forming substrate **62** have the same thermal expansivity, then it is possible to ensure even more reliable sealing of the nozzle holes **51**, without any gaps occurring between the nozzle holes **51** and the sealing members **64** when the liquid-repelling agent **76** applied to the ink ejection surface **62**A of the nozzle forming substrate **62** is made cured or semi-cured.

A desirable mode has been described as one where the sealing member **64** is formed from a uniform material, but the implementation of the present invention is not limited to this, and the interior of the sealing member **64** may be hollow, or the sealing member **64** may have layers of different materials.

Furthermore, desirably, the surface of the sealing member **64** has high liquid repelling properties and a low coefficient of friction. If the surface of the sealing members **64** has low liquid-repelling properties, then the liquid-repelling agent **76** applied to the ink ejection surface **62**A of the nozzle forming substrate **62** will flow onto the sealing members **64** and cover the sealing members **64**, and hence it will become impossible to remove the sealing members **64** from the nozzle holes **51**. Therefore, the surface of the sealing members **64** should have high liquid-repelling properties. Furthermore, in order that the sealing members **64** can be removed readily from the nozzle holes **51**, the surface of the sealing members **64** should have a low coefficient of friction. The surface of the sealing members **64** may be formed by using a resin material, such as epoxy resin, or may be coated with a thin film of a soft liquid-repelling agent, such as amorphous perfluoropolymer resins.

In the present embodiment, the shape of the nozzle hole **51** is not limited to one having the tapered section **51**A and the cylindrical section **51**B. For example, if the nozzle hole **51** is formed in an approximately cylindrical shape with no tapered section, as shown in FIG. **9**, then the sealing member **64** is composed so as to have a diameter D that is equal to or greater than the internal diameter d of the nozzle hole **51** (in other words, $D \geqq d$).

Furthermore, a more desirable mode is described as one where the nozzle hole **51** having the tapered section **51**A is sealed off by the sealing member **64** having the substantially spherical shape, but the implementation of the present invention is not limited to this, provided that the sealing member **64** is able to seal off the nozzle hole **51**, and it is also possible, for example, to seal off a nozzle hole **51** having a pentagonal prismatic shape, by means of a sealing member **64** having a pentagonal dodecahedral shape.

Furthermore, as shown in FIG. **10**, it is also possible to seal off the nozzle holes **51** together, from the side on the ink ejection surface **62**A of the nozzle forming substrate **62**, by means of a comb-shaped sealing member **64** formed as a single body.

In the present embodiment, it is possible to seal off the nozzle holes **51** readily by means of the sealing members **64**, by drawing the sealing members **64** spread over the ink ejection surface **62**A of the nozzle forming substrate **62**, by suction through the nozzle holes **51** from the side on the ink flow channel surface **62**B. Furthermore, it is also possible readily to remove the sealing members **64** sealing off the nozzle holes **51** by applying pressure from the side on the ink flow channel surface **62**B, after the liquid-repelling agent **76** has been applied to the ink ejection surface **62**A and has been cured or semi-cured. Therefore, it is possible to manufacture the nozzle plate **60** on which the liquid-repelling agent (liquid-repelling film) **76** is formed on the ink ejection surface **62**A of the nozzle forming substrate **62**, by means of the simple process.

Furthermore, in the present embodiment, it is possible to reuse the sealing members **64**. Desirably, a device is provided for detecting adhesion of the liquid-repelling agent **76** or faults in the sealing members **64**, in cases where the liquid-repelling agent **76** becomes attached to the sealing members **64**, or the sealing members **64** change in diameter due to a fault in the sealing members **64**, or the like, so that the sealing members **64** can be reused. For example, there is a method in which the sealing members **64** that are within a prescribed diameter range can be reused by passing the sealing members **64** through sieves, or a method which uses a determination device that measures the shape by means of a CCD or the like, or measures weight, or optical properties, such as the reflectivity, refractivity or transmissivity.

Furthermore, in the present embodiment, the substantially spherical sealing members **64** satisfying the above-described conditions (1) and (2) are used for the nozzle holes **51** having the tapered sections **51**A, in which the internal diameters of the nozzle holes **51** become larger toward the ends thereof on the ink ejection surface **62**A of the nozzle forming substrate **62**, and therefore, it is possible to ensure reliable clipping points, even if the nozzle plate **60** (nozzle forming substrate **62**) has a large number of nozzles or a large size. Moreover, since the sealing members **64** are constituted by the elastic bodies, then the sealing members **64** are able to make close contact with the nozzle holes **51**, without producing any gaps, and are therefore able to seal off the nozzle holes **51** in a reliable fashion.

It should be understood, however, that there is no intention to limit the invention to the specific forms disclosed, but on the contrary, the invention is to cover all modifications, alternate constructions and equivalents falling within the spirit and scope of the invention as expressed in the appended claims.

What is claimed is:

1. A method of manufacturing a nozzle plate in which a liquid-repelling film is formed on a surface of a nozzle forming substrate having nozzle holes for ejecting liquid droplets, the surface being on a droplet ejection side of the nozzle forming substrate, the method comprising the steps of:

a spreading step of spreading sealing members for sealing the nozzle holes, over the surface of the nozzle forming substrate on the droplet ejection side;

a drawing step of drawing the sealing members by suction through the nozzle holes, from another side of the nozzle forming substrate opposite to the droplet ejection side;

a first removal step of removing a surplus of the sealing members present on the surface of the nozzle forming substrate on the droplet ejection side;

an application step of applying a liquid-repelling agent onto the surface of the nozzle forming substrate on the droplet ejection side;

a curing step of curing the liquid-repelling agent applied to the surface of the nozzle forming substrate on the droplet ejection side; and

a second removal step of removing the sealing members from the nozzle holes.

2. The method as defined in claim **1**, wherein:

the curing step includes a semi-curing step of changing the liquid-repelling agent to a semi-cured state, and a full-curing step of changing the liquid-repelling agent from the semi-cured state to a fully cured state; and the liquid-repelling agent applied to the surface of the nozzle forming substrate on the droplet ejection side is changed to the semi-cured state before the second removal step, and is then changed to the fully cured state after the second removal step.

3. The method as defined in claim **1**, wherein:

the drawing step comprises a measurement step of measuring a value of suction pressure of the suction; and

the drawing step is performed until the measured value of the suction pressure becomes not less than a prescribed value.

4. The method as defined in claim **1**, wherein the nozzle holes have at least partially tapered shapes in which internal diameters of the nozzle holes become larger toward ends thereof on the surface of the nozzle forming substrate on the droplet ejection side.

5. The method as defined in claim **1**, wherein the sealing members have a substantially spherical shape.

6. The method as defined in claim **1**, wherein the sealing members are made of elastic bodies.

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